TRANSACTIONS

OF THE

ROYAL SOCIETY

OF

EDINBURGH.

VOL. XXVI.

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MDCCCLXXII.

BRITISH MUSEUM
NATURAL HISTORY.

ROYAL SOCIETY OF EDINBURGH.

THE KEITH, BRISBANE, AND NEILL PRIZES.

The above Prizes will be awarded by the Council in the following manner:—

I. KEITH PRIZE.

The KEITH PRIZE, consisting of a Gold Medal and from £40 to £50 in Money, will be awarded in the Session 1873–74, for the "best communication on a scientific subject, communicated, in the first instance, to the Royal Society during the Sessions 1871–72 and 1872–73." Preference will be given to a paper containing a discovery.

II. MAKDOUGALL BRISBANE PRIZE.

This Prize is to be awarded biennially by the Council of the Royal Society of Edinburgh to such person, for such purposes, for such objects, and in such manner as shall appear to them the most conducive to the promotion of the interests of science; with the *proviso* that the Council shall not be compelled to award the Prize unless there shall be some individual engaged in scientific pursuit, or some paper written on a scientific subject, or some discovery in science made during the biennial period, of sufficient merit or importance in the opinion of the Council to be entitled to the Prize.

1. The Prize, consisting of a Gold Medal and a sum of Money, will be awarded at the commencement of the Session 1874–75, for an Essay or Paper having reference to any branch of scientific inquiry, whether Material or Mental.

2. Competing Essays to be addressed to the Secretary of the Society, and transmitted not later than 1st June 1874.

3. The Competition is open to all men of science.

4. The Essays may be either anonymous or otherwise. In the former case, they must be distinguished by mottoes, with corresponding sealed billets superscribed with the same motto, and containing the name of the Author.

5. The Council impose no restriction as to the length of the Essays, which may be, at the discretion of the Council, read at the Ordinary Meetings of the Society. They wish also to leave the property and free disposal of the manuscripts to the Authors; a copy, however, being deposited in the Archives of the Society, unless the Paper shall be published in the Transactions.

6. In awarding the Prize, the Council will also take into consideration any scientific papers presented to the Society during the Sessions 1872–73 and 1873–74, whether they may have been given in with a view to the Prize or not.

III. NEILL PRIZE.

The Council of the Royal Society of Edinburgh having received the bequest of the late Dr PATRICK NEILL of the sum of £500, for the purpose of "the interest thereof being applied in furnishing a Medal or other reward every second or third year to any distinguished Scottish Naturalist, according as such Medal or reward shall be voted by the Council of the said Society," hereby intimate,

1. The NEILL PRIZE, consisting of a Gold Medal and a sum of Money, will be awarded during the Session 1874–75.

2. The Prize will be given for a Paper of distinguished merit, on a subject of Natural History, by a Scottish Naturalist, which shall have been presented to the Society during the three years preceding the 1st May 1874,—or failing presentation of a paper sufficiently meritorious, it will be awarded for a work or publication by some distinguished Scottish Naturalist, on some branch of Natural History, bearing date within five years of the time of award.

AWARDS OF THE KEITH, MAKDOUGALL BRISBANE, AND NEILL PRIZES, FROM 1827 TO 1872.

I. KEITH PRIZE.

1st Biennial Period, 1827–29.—Dr Brewster, for his papers "on his Discovery of Two New Immiscible Fluids in the Cavities of certain Minerals," published in the Transactions of the Society.

2d Biennial Period, 1829–31.—Dr Brewster, for his paper "on a New Analysis of Solar Light," published in the Transactions of the Society.

3d Biennial Period, 1831–33.—Thomas Graham, Esq., for his paper "on the Law of the Diffusion of Gases," published in the Transactions of the Society.

4th Biennial Period, 1833–35.—Professor Forbes, for his paper "on the Refraction and Polarization of Heat," published in the Transactions of the Society.

5th Biennial Period, 1835–37.—John Scott Russell, Esq., for his Researches "on Hydrodynamics," published in the Transactions of the Society.

6th Biennial Period, 1837–39.—Mr John Shaw, for his Experiments "on the Development and Growth of the Salmon," published in the Transactions of the Society.

7th Biennial Period, 1839–41.—Not awarded.

8th Biennial Period, 1841–43.—Professor Forbes, for his Papers "on Glaciers," published in the Proceedings of the Society.

9th Biennial Period, 1843–45.—Not awarded.

10th Biennial Period, 1845–47.—General Sir Thomas Brisbane, Bart., for the Makerstoun Observations on Magnetic Phenomena, made at his expense, and published in the Transactions of the Society.

11th Biennial Period, 1847–49.—Not awarded.

12th Biennial Period, 1849–51.—Professor Kelland, for his papers "on General Differentiation, including his more recent communication on a process of the Differential Calculus, and its application to the solution of certain Differential Equations," published in the Transactions of the Society.

13th Biennial Period, 1851–53.—W. J. Macquorn Rankine, Esq., for his series of papers "on the Mechanical Action of Heat," published in the Transactions of the Society.

14th Biennial Period, 1853–55.—Dr Thomas Anderson, for his papers "on the Crystalline Constituents of Opium, and on the Products of the Destructive Distillation of Animal Substances," published in the Transactions of the Society.

15TH BIENNIAL PERIOD, 1855–57.—Professor BOOLE, for his Memoir "on the Application of the Theory of Probabilities to Question of the Combination of Testimonies and Judgments," published in the Transactions of the Society.

16TH BIENNIAL PERIOD, 1857–59.—Not awarded.

17TH BIENNIAL PERIOD, 1859–61.—JOHN ALLAN BROUN, Esq., F.R.S., Director of the Trevandrum Observatory, for his papers "on the Horizontal Force of the Earth's Magnetism, on the Correction of the Bifilar Magnetometer, and on Terrestrial Magnetism generally," published in the Transactions of the Society.

18TH BIENNIAL PERIOD, 1861–63.—Professor WILLIAM THOMSON, of the University of Glasgow, for his Communication "on some Kinematical and Dynamical Theorems," published in the Transactions of the Society.

19TH BIENNIAL PERIOD, 1863–65.—Principal FORBES, St Andrews, for his "Experimental Inquiry into the Laws of Conduction of Heat in Iron Bars," published in the Transactions of the Society.

20TH BIENNIAL PERIOD, 1865–67.—Professor C. PIAZZI SMYTH, for his paper "on Recent Measures at the Great Pyramid," published in the Transactions of the Society.

21ST BIENNIAL PERIOD, 1867–69.—Professor P. G. TAIT, for his paper "on the Rotation of a Rigid Body about a Fixed Point," published in the Transactions of the Society.

22D BIENNIAL PERIOD, 1869–71.—Professor CLERK MAXWELL, for his paper "on Figures, Frames, and Diagrams of Forces," published in the Transactions of the Society.

II. MAKDOUGALL BRISBANE PRIZE.

1ST BIENNIAL PERIOD, 1859.—Sir RODERICK IMPEY MURCHISON, on account of his Contributions to the Geology of Scotland.

2D BIENNIAL PERIOD, 1860–62.—WILLIAM SELLER, M.D., F.R.C.P.E., for his "Memoir of the Life and Writings of Dr Robert Whytt," published in the Transactions of the Society.

3D BIENNIAL PERIOD, 1862–64.—JOHN DENIS MACDONALD, Esq., R.N., F.R.S., Surgeon of H.M.S. "Icarus," for his paper "on the Representative Relationships of the Fixed and Free Tunicata, regarded as two Sub-classes of equivalent value; with some General Remarks on their Morphology," published in the Transactions of the Society.

4TH BIENNIAL PERIOD, 1864–66.—Not awarded.

5TH BIENNIAL PERIOD, 1866–68.—Dr ALEXANDER CRUM BROWN, and Dr THOMAS RICHARD FRASER, for their conjoint paper "on the Connection between Chemical Constitution and Physiological Action," published in the Transactions of the Society.

6TH BIENNIAL PERIOD, 1868–70.—Not awarded.

7TH BIENNIAL PERIOD, 1870–72.—GEORGE JAMES ALLMAN, M.D., F.R.S., Emeritus Professor of Natural History, for his paper 'on the Homological Relations of the Cœlenterata,' published in the Transactions, which forms a leading chapter of his Monograph of Gymnoblastic or Tubularian Hydroids—since published.

III. NEILL PRIZE.

1st Triennial Period, 1856–59.—Dr W. Lauder Lindsay, for his paper "on the Spermogones and Pycnides of Filamentous, Fruticulose, and Foliaceous Lichens," published in the Transactions of the Society.

2d Triennial Period, 1859–62.—Robert Kaye Greville, LL.D., for his Contributions to Scottish Natural History, more especially in the department of Cryptogamic Botany, including his recent papers on Diatomaceæ.

3d Triennial Period, 1862–65.—Andrew Crombie Ramsay, F.R.S., Professor of Geology in the Government School of Mines, and Local Director of the Geological Survey of Great Britain, for his various Works and Memoirs published during the last five years, in which he has applied the large experience acquired by him in the Direction of the arduous work of the Geological Survey of Great Britain to the elucidation of important questions bearing on Geological Science.

4th Triennial Period, 1865–68.—Dr William Carmichael M'Intosh, for his paper "on the Structure of the British Nemerteans, and on some New British Annelids," published in the Transactions of the Society.

5th Triennial Period, 1868–71.—Professor Turner, for his papers "on the great Finner Whale; and on the Gravid Uterus, and the Arrangement of the Fœtal Membranes in the Cetacea," published in the Transactions of the Society.

LAWS

OF THE

ROYAL SOCIETY OF EDINBURGH,

AS REVISED JANUARY 1873.

LAWS.

[By the Charter of the Society (printed in the *Transactions*, Vol. VI. p. 5.), the Laws cannot be altered, except at a Meeting held one month after that at which the Motion for alteration shall have been proposed.]

I.

THE ROYAL SOCIETY OF EDINBURGH shall consist of Ordinary and Honorary Fellows. Title.

II.

Every Ordinary Fellow, within three months after his election, shall pay Two Guineas as the fee of admission, and Three Guineas as his contribution for the Session in which he has been elected; and annually at the commencement of every Session, Three Guineas into the hands of the Treasurer. This annual contribution shall continue for ten years after his admission, and it shall be limited to Two Guineas for fifteen years thereafter.* The fees of Ordinary Fellows residing in Scotland.

III.

All Fellows who shall have paid Twenty-five years' annual contribution shall be exempted from farther payment. Payment to cease after 25 years.

IV.

The fees of admission of an Ordinary Non-Resident Fellow shall be £26, 5s., payable on his admission; and in case of any Non-Resident Fellow coming to reside at any time in Scotland, he shall, during each year of his residence, pay the usual annual contribution of £3, 3s., payable by each Resident Fellow; but after payment of such annual contribution for eight years, he shall be exempt from any farther payment. In the case of any Resident Fellow ceasing to reside Fees of Non-Resident Ordinary Fellows.

Case of Fellows becoming Non-Resident.

* At the Meeting of the Society, on the 5th January 1857, when the reduction of the Contributions from £3, 3s., to £2, 2s., from the 11th to the 25th year of membership, was adopted, it was resolved that the existing Members shall share in this reduction, so far as regards their future annual Contributions.

A modification of this rule, in certain cases, was agreed to 3d January 1831.

in Scotland, and wishing to continue a Fellow of the Society, it shall be in the power of the Council to determine on what terms, in the circumstances of each case, the privilege of remaining a Fellow of the Society shall be continued to such Fellow while out of Scotland.

V.

Defaulters.

Members failing to pay their contributions for three successive years (due application having been made to them by the Treasurer) shall be reported to the Council, and, if they see fit, shall be declared from that period to be no longer Fellows, and the legal means for recovering such arrears shall be employed.

VI.

Privileges of Ordinary Fellows.

None but Ordinary Fellows shall bear any office in the Society, or vote in the choice of Fellows or Office-Bearers, or interfere in the patrimonial interests of the Society.

VII.

Numbers Unlimited.

The number of Ordinary Fellows shall be unlimited.

VIII.

Fellows entitled to Transactions.

The Ordinary Fellows, upon producing an order from the TREASURER, shall be entitled to receive from the Publisher, gratis, the Parts of the Society's Transactions which shall be published subsequent to their admission.

IX.

Mode of Recommending Ordinary Fellows.

Candidates for admission as Ordinary Fellows shall make an application in writing, and shall produce along with it a certificate of recommendation to the purport below,* signed by at least *four* Ordinary Fellows, two of whom shall certify their recommendation from personal knowledge. This recommendation shall be delivered to the Secretary, and by him laid before the Council, and shall afterwards be printed in the circulars for three Ordinary Meetings of the Society, previous to the day of election, and shall lie upon the table during that time.

X.

Honorary Fellows, British and Foreign.

Honorary Fellows shall not be subject to any contribution. This class shall

* "A. B., a gentleman well versed in Science (*or Polite Literature, as the case may be*), being "to our knowledge desirous of becoming a Fellow of the Royal Society of Edinburgh, we hereby "recommend him as deserving of that honour, and as likely to prove a useful and valuable Member."

consist of persons eminently distinguished for science or literature. Its number shall not exceed Fifty-six, of whom Twenty may be British subjects, and Thirty-six may be subjects of foreign states.

XI.

Personages of Royal Blood may be elected Honorary Fellows, without regard to the limitation of numbers specified in Law X. Royal Personages.

XII.

Honorary Fellows may be proposed by the Council, or by a recommendation (in the form given below*) subscribed by three Ordinary Fellows; and in case the Council shall decline to bring this recommendation before the Society, it shall be competent for the proposers to bring the same before a General Meeting. The election shall be by ballot, after the proposal has been communicated *viva voce* from the Chair at one meeting, and printed in the circulars for two ordinary meetings of the Society, previous to the day of election. Recommendation of Honorary Fellows. Mode of Election.

XIII.

The election of Ordinary Fellows shall only take place at the first Ordinary Meeting of each month during the Session. The election shall be by ballot, and shall be determined by a majority of at least two-thirds of the votes, provided Twenty-four Fellows be present and vote. Election of Ordinary Fellows.

XIV.

The Ordinary Meetings shall be held on the first and third Mondays of every month from November to June inclusively. Regular Minutes shall be kept of the proceedings, and the Secretaries shall do the duty alternately, or according to such agreement as they may find it convenient to make. Ordinary Meetings.

XV.

The Society shall from time to time publish its Transactions and Proceedings. For this purpose the Council shall select and arrange the papers which The Transactions.

* We hereby recommend_____
for the distinction of being made an Honorary Fellow of this Society, declaring that each of us from our own knowledge of his services to (*Literature or Science, as the case may be*) believe him to be worthy of that honour.

(To be signed by three Ordinary Fellows.)

_____

_____

_____

To the President and Council of the Royal Society of Edinburgh.

they shall deem it expedient to publish in the *Transactions* of the Society, and shall superintend the printing of the same.

XVI.

How Published.

The Transactions shall be published in parts or *Fasciculi* at the close of each Session, and the expense shall be defrayed by the Society.

XVII.

The Council.

There shall be elected annually, for conducting the publications and regulating the private business of the Society, a Council, consisting of a President; Six Vice-Presidents, two at least of whom shall be resident; Twelve Councillors, a General Secretary, Two Secretaries to the Ordinary Meetings, a Treasurer, and a Curator of the Museum and Library.

XVIII.

Retiring Councillors.

Four Councillors shall go out annually, to be taken according to the order in which they stand on the list of the Council.

XIX.

Election of Office-Bearers.

An Extraordinary Meeting for the Election of Office-Bearers shall be held on the fourth Monday of November annually.

XX.

Special Meetings; how called.

Special Meetings of the Society may be called by the Secretary, by direction of the Council; or on a requisition signed by six or more Ordinary Fellows. Notice of not less than two days must be given of such Meetings.

XXI.

Treasurer's Duties.

The Treasurer shall receive and disburse the money belonging to the Society, granting the necessary receipts, and collecting the money when due.

He shall keep regular accounts of all the cash received and expended, which shall be made up and balanced annually; and at the Extraordinary Meeting in November, he shall present the accounts for the preceding year, duly audited. At this Meeting, the Treasurer shall also lay before the Council a list of all arrears due above two years, and the Council shall thereupon give such directions as they may deem necessary for recovery thereof.

XXII.

Auditor.

At the Extraordinary Meeting in November, a professional accountant shall be chosen to audit the Treasurer's accounts for that year, and to give the necessary discharge of his intromissions.

XXIII.

General Secretary's Duties.

The General Secretary shall keep Minutes of the Extraordinary Meetings of the Society, and of the Meetings of the Council, in two distinct books. He shall, under the direction of the Council, conduct the correspondence of the Society, and superintend its publications. For these purposes he shall, when necessary, employ a clerk, to be paid by the Society.

XXIV.

Secretaries to Ordinary Meetings

The Secretaries to the Ordinary Meetings shall keep a regular Minute-book, in which a full account of the procedings of these Meetings shall be entered; they shall specify all the Donations received, and furnish a list of them, and of the Donors' names, to the Curator of the Library and Museum; they shall likewise furnish the Treasurer with notes of all admissions of Ordinary Fellows. They shall assist the General Secretary in superintending the publications, and in his absence shall take his duty.

XXV.

Curator of Museum and Library.

The Curator of the Museum and Library shall have the custody and charge of all the Books, Manuscripts, objects of Natural History, Scientific Productions, and other articles of a similar description belonging to the Society; he shall take an account of these when received, and keep a regular catalogue of the whole, which shall lie in the Hall, for the inspection of the Fellows.

XXVI.

Use of Museum and Library.

All Articles of the above description shall be open to the inspection of the Fellows at the Hall of the Society, at such times and under such regulations, as the Council from time to time shall appoint.

XXVII.

Register Book.

A Register shall be kept, in which the names of the Fellows shall be enrolled at their admission, with the date.

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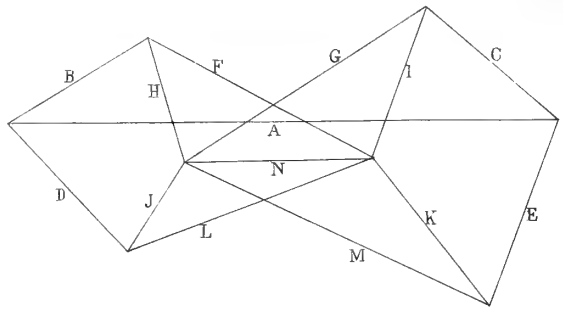

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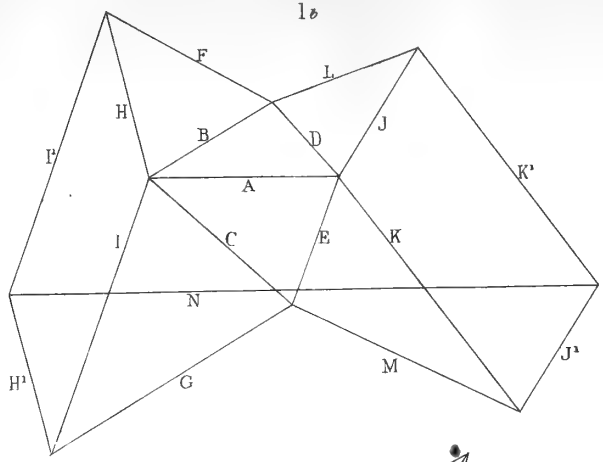

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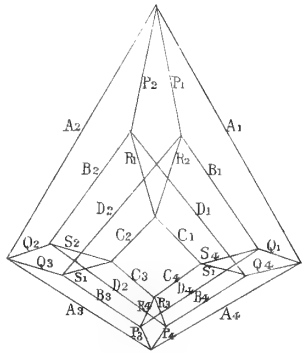

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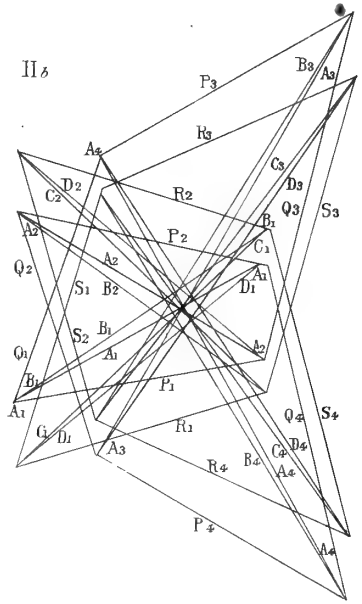

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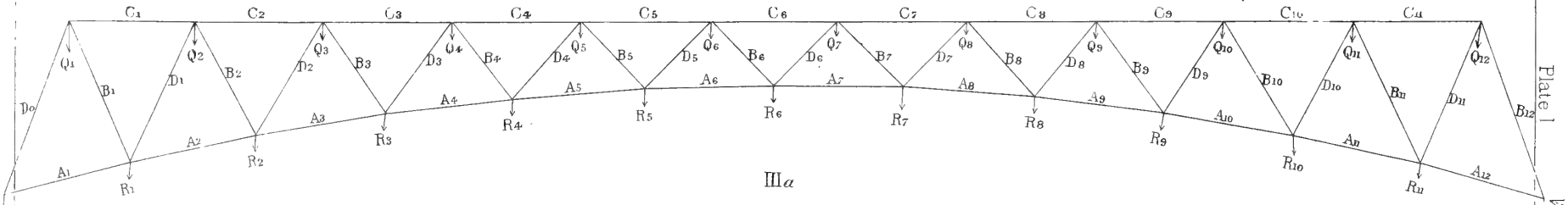
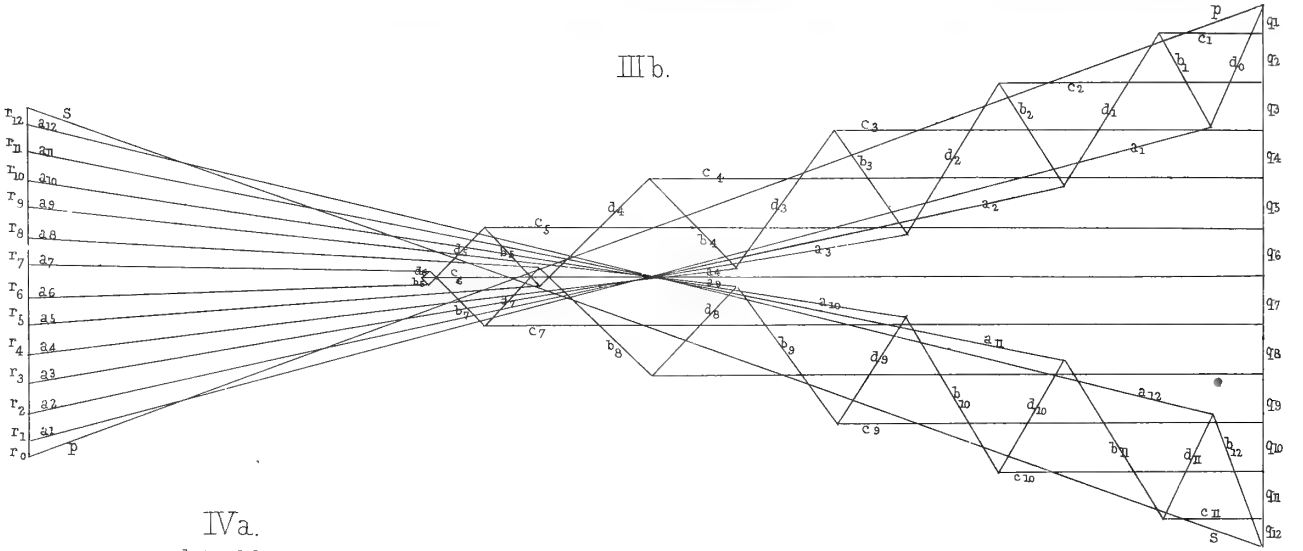
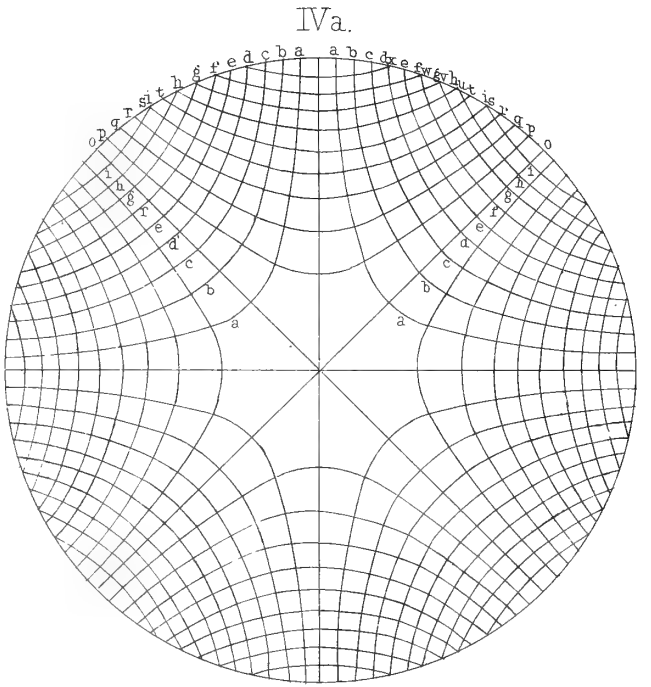
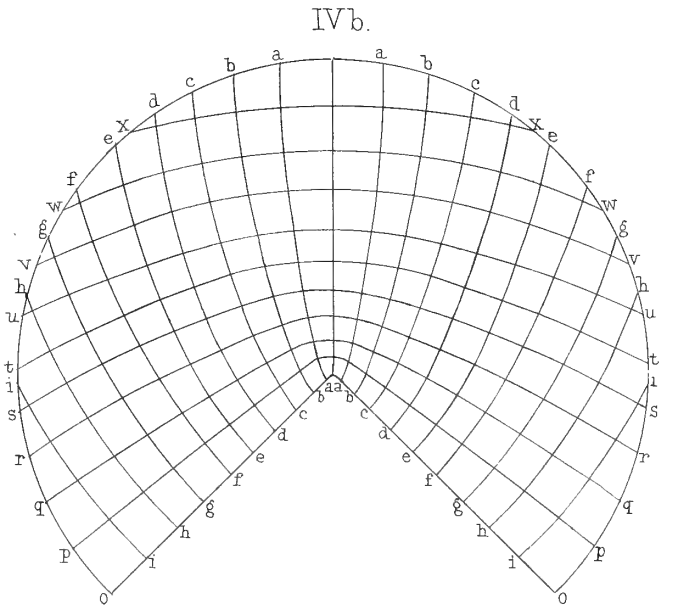


IIIa

W & A K. Johnston Edinburgh







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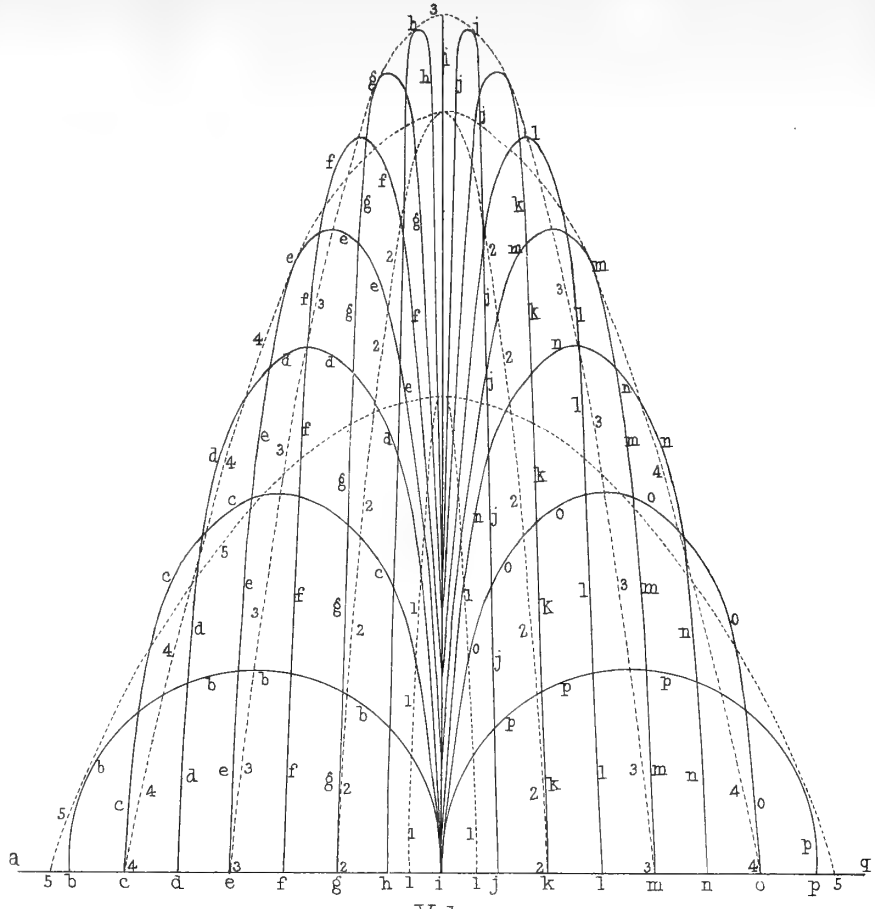

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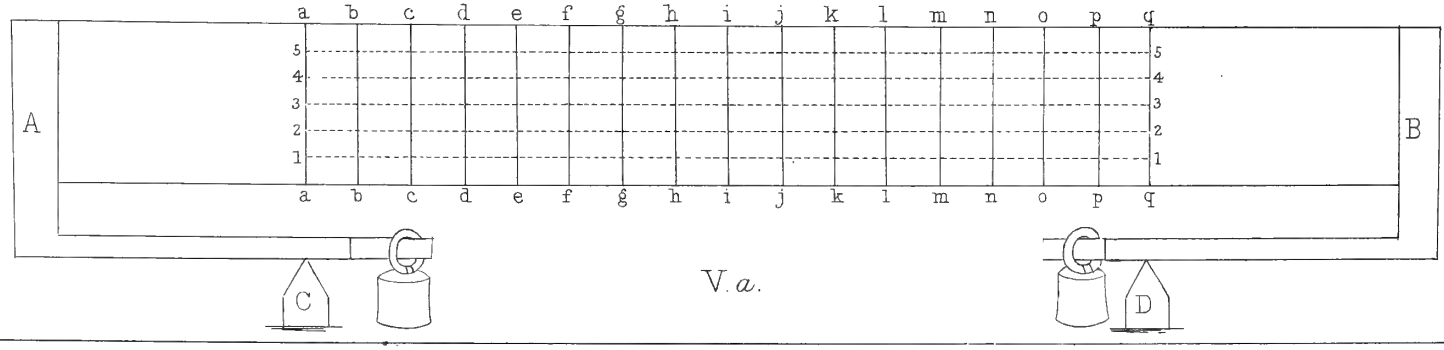


V. *a*.

W. & A.K. Johnston, Edinburgh.

TRANSACTIONS.

I.—*On Reciprocal Figures, Frames, and Diagrams of Forces.* By J. Clerk Maxwell, F.R.SS. L. & E. (Plates I. II. III.)

(Received 17th Dec. 1869; read 7th Feb. 1870.)

Two figures are reciprocal when the properties of the first relative to the second are the same as those of the second relative to the first. Several kinds of reciprocity are known to mathematicians, and the theories of Inverse Figures and of Polar Reciprocals have been developed at great length, and have led to remarkable results. I propose to investigate a different kind of geometrical reciprocity, which is also capable of considerable development, and can be applied to the solution of mechanical problems.

A Frame may be defined geometrically as a system of straight lines connecting a number of points. In actual structures these lines are material pieces, beams, rods, or wires, and may be straight or curved; but the force by which each piece resists any alteration of the distance between the points which it joins acts in the straight line joining those points. Hence, in studying the equilibrium of a frame, we may consider its different points as mutually acting on each other with forces whose directions are those of the lines joining each pair of points. When the forces acting between the two points tend to draw them together, or to prevent them from separating, the action along the joining line is called a Tension. When the forces tend to separate the points, or to keep them apart, the action along the joining line is called a Pressure.

If we divide the piece joining the points by any imaginary section, the resultant of the whole internal force acting between the parts thus divided will be mechanically equivalent to the tension or pressure of the piece. Hence, in order to exhibit the mechanical action of the frame in the most elementary manner, we may draw it as a skeleton, in which the different points are joined by straight lines, and we may indicate by numbers attached to these lines the tensions or pressures in the corresponding pieces of the frame.

The diagram thus formed indicates the state of the frame in a way which is

geometrical as regards the position and direction of the forces, but arithmetical as regards their magnitude.

But, by assuming that a line of a certain length shall represent a force of a certain magnitude, we may represent every force completely by a line. This is done in Elementary Statics, where we are told to draw a line from the point of application of the force in the direction in which the force acts, and to cut off as many units of length from the line as there are units of force in the force, and finally to mark the end of the line with an arrow-head, to show that it is a force and not a piece of the frame, and that it acts in that direction and not the opposite.

By proceeding in this way, we should get a system of arrow-headed forces superposed on the skeleton of the frame, two equal and opposite arrows for every piece of the frame.

To test the equilibrium of these forces at any point of concourse, we should proceed by the construction of the parallelogram of forces, beginning with two of the forces acting at the point, completing the parallelogram, and drawing the diagonal, and combining this with the third force in the same way, till, when all the forces had been combined, the resultant disappeared. We should thus have to draw three new lines, one of which is an arrow, in taking in each force after the first, leaving at last not only a great number of useless lines, but a number of new arrows, not belonging to the system of forces, and only confusing to any one wishing to verify the process.

To simplify this process, we are told to construct the Polygon of Forces, by drawing in succession lines parallel and proportional to the different forces, each line beginning at the extremity of the last. If the forces acting at the point are in equilibrium, the polygon formed in this way will be a closed one.

Here we have for the first time a true Diagram of Forces, in which every force is not only represented in magnitude and direction by a straight line, but the equilibrium of the forces is manifest by inspection, for we have only to examine whether the polygon is closed or not. To secure this advantage, however, we have given up the attempt to indicate the position of the force, for the sides of the polygon do not pass through one point as the forces do. We must, therefore, give up the plan of representing the frame and its forces in one diagram, and draw one diagram of the frame and a separate diagram of the forces. By this method we shall not only avoid confusion, but we shall greatly simplify mechanical calculations, by reducing them to operations with the parallel ruler, in which no useless lines are drawn, but every line represents an actual force.

A Diagram of Forces is a figure, every line of which represents in magnitude and direction the force acting along a piece of the frame.

To express the relation between the diagram of the frame and the diagram of forces, the lines of the frame should each be indicated by a symbol, and the

corresponding lines of the diagram of forces should be indicated by the same symbol, accented if necessary.

We have supposed the corresponding lines to be parallel, and it is necessary that they should be parallel when the frame is not in one plane; but if all the pieces of the frame are parallel to one plane, we may turn one of the diagrams round a right angle, and then every line will be perpendicular to the corresponding line.

If any number of lines meet at the same point in the frame, the corresponding lines in the diagram of forces form a closed polygon.

It is possible, in certain cases, to draw the diagram of forces so that if any number of lines meet in a point in the diagram of forces, the corresponding lines in the frame form a closed polygon.

In such cases, the two diagrams are said to be reciprocal in the sense in which we use it in this paper. If either diagram be taken as representing the frame, the lines of the other diagram will represent a system of forces which, if applied along the corresponding pieces of the frame, will keep it in equilibrium.

The properties of the "triangle" and "polygon" of forces have been long known, and a "diagram" of forces has been used in the case of the "funicular polygon," but I am not aware of any more general statement of the method of drawing diagrams of forces before Professor RANKINE applied it to frames, roofs, &c., in his "Applied Mechanics," p. 137, &c. The "polyhedron of forces," or the proposition that forces acting on a point perpendicular and proportional to the areas of the faces of a polyhedron are in equilibrium, has, I believe, been enunciated independently at various times, but the application of this principle to the construction of a diagram of forces in three dimensions was first made by Professor RANKINE in the "Philosophical Magazine," Feb. 1864. In the "Philosophical Magazine" for April 1864, I stated some of the properties of reciprocal figures, and the conditions of their existence, and showed that any plane rectilinear figure which is a perspective representation of a closed polyhedron with plane faces has a reciprocal figure. In Sept. 1867, I communicated to the British Association a method of drawing the reciprocal figure, founded on the theory of reciprocal polars.

I have since found that the construction of diagrams of forces in which each force is represented by one line, had been independently discovered by Mr W. P. TAYLOR, and had been used by him as a practical method of determining the forces acting in frames for several years before I had taught it in King's College, or even studied it myself. I understand that he is preparing a statement of the application of the method to various kinds of structures in detail, so that it can be made use of by any one who is able to draw one line parallel to another.

Professor Fleeming Jenkin, in a paper recently published by the Society, has fully explained the application of the method to the most important cases occurring in practice.

In the present paper I propose, first, to consider plane diagrams of frames and of forces in an elementary way, as a practical method of solving questions about the stresses in actual frameworks, without the use of long calculations.

I shall then discuss the subject in a theoretical point of view, and give a method of defining reciprocal diagrams analytically, which is applicable to figures either of two or of three dimensions.

Lastly, I shall extend the method to the investigation of the state of stress in a continuous body, and shall point out the nature of the function of stress first discovered by the Astronomer Royal for stresses in two dimensions, extending the use of such functions to stresses in three dimensions.

On Reciprocal Plane Rectilinear Figures.

Definition.—Two plane rectilinear figures are reciprocal when they consist of an equal number of straight lines, so that corresponding lines in the two figures are at right angles, and corresponding lines which meet in a point in the one figure form a closed polygon in the other.

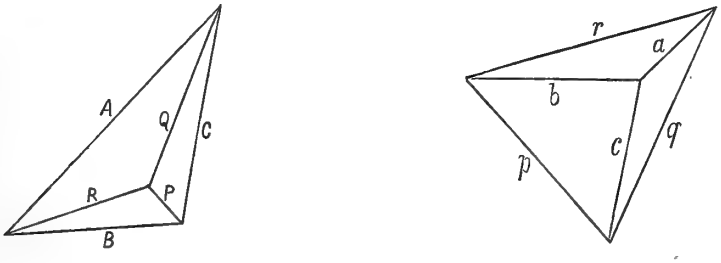
Note.—It is often convenient to turn one of the figures round in its own plane 90°. Corresponding lines are then parallel to each other, and this is sometimes more convenient in comparing the diagrams by the eye.

Since every polygon in the one figure has three or more sides, every point in the other figure must have three or more lines meeting in it. Since every line in the one figure has two, and only two, extremities, every line in the other figure must be a side of two, and only two, polygons. If either of these figures be taken to represent the pieces of a frame, the other will represent a system of forces such that, these forces being applied as tensions or pressures along the corresponding pieces of the frame, every point of the frame will be in equilibrium.

The simplest example is that of a triangular frame without weight, ABC, jointed at the angles, and acted on by three forces, P, Q, R, applied at the angles. The directions of these three forces must meet in a point, if the frame is in equilibrium. We shall denote the lines of the figure by capital letters, and those of the reciprocal figure by the corresponding small letters; we shall denote points by the lines which meet in them, and polygons by the lines which bound them.

Here, then, are three lines, A, B, C, forming a triangle, and three other lines, P, Q, R, drawn from the angles and meeting in a point. Of these forces let that along P be given. Draw the first line p of the reciprocal diagram parallel to P, and of a length representing, on any convenient scale, the force along P. The forces along P, Q, R are in equilibrium, therefore, if from one

extremity of p we draw q parallel to Q, and from the other extremity r parallel to R, so as to form a triangle pqr, then q and r will represent on the same scale the forces along Q and R.



To determine whether these forces are tensions or pressures, make a point travel along p in the direction in which the force in P acts on the point of concourse of PQR, and let the point travel in the same direction round the polygon pqr. Then, the direction in which the point travels along any side of the polygon will be the direction in which the force acts along the corresponding piece of the frame on the point of concourse. If it acts from the point of concourse, the force is a tension; if towards it, it is a pressure.

The other extremity of P meets B and C, and the forces along these three pieces are in equilibrium. Hence, if we draw a triangle, having p for one side and lines parallel to B and C for the others, the sides of this triangle will represent the three forces.

Such a triangle may be described on either side of p, the two together would form a parallelogram of forces; but the theory of reciprocal figures indicates that only one of these triangles forms part of the diagram of forces.

The rule for such cases is as follows:—Of the two extremities of p, one corresponds to the closed figure PRB, and the other to the closed figure PQC, these being the polygons of which P is a side in the first figure.

We must, therefore, draw b parallel to B from the intersection of p and r, and not from the other extremity, and we must draw c parallel to C from the intersection of p and q.

We have now a second triangle, pbc, corresponding to the forces acting at the point of concourse of P, B, C. To determine whether these forces are tensions or pressures, we must make a point travel round pbc, so that its course along p is in the opposite direction to its course round pqr, because the piece P acts on the points PBC and PQR with equal and opposite forces.

If we now consider the equilibrium of the point of concourse of QC and A, we shall find that we have determined two of these forces by the lines q and c, and that the third force must be represented by the line a which completes the triangle qca.

We have now constructed a complete diagram of forces, in which each force

is represented by a single line, and in which the equilibrium of the forces meeting at any point is expressed visibly by the corresponding lines in the other figure forming a closed polygon.

There are in this figure six lines, having four points of concourse, and forming four triangles. To determine the direction of the force along a given line at any point of concourse, we must make a point travel round the corresponding polygon in the other figure in a direction which is positive with respect to that polygon. For this purpose it is desirable to name the polygons in a determinate order of their sides, so arranged that, when we arrive at the same side in naming the two polygons which it divides, we travel along it in opposite directions. For instance, if *pqr* be one of the polygons, the others are *pbc*, *qca*, *rab*.

Note.—It may be observed, that after drawing the lines *p*, *q*, *r*, *b*, *c* with the parallel ruler, the line *a* was drawn by joining the points of concourse of *q*, *r* and *b*, *c*; but, since it represents the force in A, *a* is parallel to A. Hence the following geometrical theorem :—

If the lines PQR, drawn from the angles of the triangle ABC, meet in a point, then if *pqr* be a triangle with its corresponding sides parallel to P, Q, R, and if *a*, *b*, *c* be drawn from its corresponding angles parallel to A, B, C, the lines *a*, *b*, *c* will meet in a point.

A geometrical proof of this is easily obtained by finding the centres of the four circles circumscribing the triangles ABC, AQR, BRP, CPQ, and joining the four centres thus found by six lines.

These lines meet in the four centres, and are perpendicular to the six lines, A, B, C ; P, Q, R ; but by turning them round 90° they become parallel to the corresponding lines in the original figure.

The diagram formed in this way is definite in size and position, but any figure similar to it is a reciprocal diagram to the original figure. I have explained the construction of this, the simplest diagram of forces, more at length, as I wish to show how, after the first line is drawn and its extremities fixed on, every other line is drawn in a perfectly definite position by means of the parallel ruler.

In any complete diagram of forces, those forces which act at a given point in the frame form a closed polygon. Hence, there will be as many closed polygons in the diagram as there are points in the frame. Also, since each piece of the frame acts with equal and opposite forces on the two points which form its extremities, the force in the diagram will be a side of two different polygons. These polygons might be drawn in any positions relatively to each other ; but, in the diagrams here considered, they are placed so that each force is represented by one line, which forms the boundary between the two polygons to which it belongs.

If we regard the polygons as surfaces, rather than as mere outlines, every

polygon will be bounded at every point of its outline by other polygons, so that the whole assemblage of polygons will form a continuous surface, which must either be an infinite surface or a closed surface.

The diagram cannot be infinite, because it is made up of a finite number of finite lines representing finite forces. It must, therefore, be a closed surface returning on itself, in such a way that every point in the plane of the diagram either does not belong to the diagram at all, or belongs to an even number of sheets of the diagram.

Any system of polygons, which are in contact with each other externally, may be regarded as a sheet of the diagram. When two polygons are on the same side of the line, which is common to them, that line forms part of the common boundary of two sheets of the diagram. If we reckon those areas positive, the boundary of which is traced in the direction of positive rotation round the area, then all the polygons in each sheet will be of the same sign as the sheet, but those sheets which have a common boundary will be of opposite sign. At every point in the diagram there will be the same number of positive as of negative sheets, and the whole area of the positive sheets will be equal to that of the negative sheets.

The diagram, therefore, may be considered as a plane projection of a closed polyhedron, the faces of the polyhedron being surfaces bounded by rectilinear polygons, which may or may not, as far as we yet know, lie each in one plane.

Let us next consider the plane projection of a given closed polyhedron. If any of the faces of this polyhedron are not plane, we may, by drawing additional lines, substitute for that face a system of triangles, each of which is necessarily in a plane. We may, therefore, consider the polyhedron as bounded by plane faces. Every angular point of this polyhedron will be defined by its projection on the plane and its height above it.

Let us now take a fixed point, which we shall call the origin, and draw from it a perpendicular to the plane. We shall call this line the axis. If we then draw from the origin a line perpendicular to one of the faces of the polyhedron, it will cut the plane at a point which may be said to correspond to the projection of that face. From this point draw a line perpendicular to the plane, and take on this line a point whose distance from the plane is equal to that of the intersection of the axis with the face of the polyhedron produced, but on the other side of the plane. This point in space will correspond to the face of the polyhedron. By repeating this process for every face of the polyhedron, we shall find for every face a corresponding point with its projection on the plane.

To every edge of the polyhedron will correspond the line which joins the points corresponding to the two faces which meet in that edge. Each of these lines is perpendicular to the projection of the other; for the perpendiculars from the origin to the two faces, lie in a plane perpendicular to the edge in

which they meet, and the projection of the line corresponding to the edge is the intersection of this plane with the plane of projection. Hence, the edge is perpendicular to the projection of the corresponding line. The projection of the edge is therefore perpendicular to the projection of the corresponding line, and therefore to the corresponding line itself. In this way we may draw a diagram on the plane of projection, every line of which is perpendicular to the corresponding line in the original figure, and so that lines which meet in a point in the one figure form a closed polygon in the other.

If, in a system of rectangular co-ordinates, we make $z=0$ the plane of projection, and $x=0$ $y=0$ $z=-c$ the fixed point, then if the equation of a plane be

$$z = \mathrm{A}x + \mathrm{B}y + \mathrm{C}\,,$$

the co-ordinates of the corresponding point will be

$$\xi = c\mathrm{A} \qquad \eta = c\mathrm{B} \qquad \zeta = -\mathrm{C}\,,$$

and we may write the equation

$$c(z+\zeta) = x\xi + y\eta\,.$$

If we suppose ξ, η, ζ given as the co-ordinates of a point, then this equation, considering x, y, z as variable, is the equation of a plane corresponding to the point.

If we suppose x, y, z the co-ordinates of a point, and ξ, η, ζ as variable, the equation will be that of a plane corresponding to that point.

Hence, if a plane passes through the point xyz, the point corresponding to this plane lies in the plane corresponding to the point xyz.

These points and planes are reciprocally polar in the ordinary sense with respect to the paraboloid of revolution

$$2cz = x^2 + y^2\,.$$

We have thus arrived at a construction for reciprocal diagrams by considering each as a plane projection of a plane-sided polyhedron, these polyhedra being reciprocal to one another, in the geometrical sense, with respect to a certain paraboloid of revolution.

Each of the diagrams must fulfil the conditions of being a plane projection of a plane-sided polyhedron, for if any of the sides of the polyhedron of which it is the projection are not plane, there will be as many points corresponding to that side as there are different planes passing through three points of the side, and the other diagram will be indefinite.

Relation between the Number of Edges, Summits, and Faces of Polyhedra.

It is manifest that after a closed surface has been divided into separate faces by lines drawn upon it, every new line drawn from a point in the system, either introduces one new point into the system, or divides a face into two parts,

according as it is drawn to an isolated point, or to a point already connected with the system. Hence the sum of points and faces is increased by one for every new line. If the closed surface is acyclic, or simply connected,* like that of a solid body without any passage through it, then, if from any point we draw a closed curve on the surface, we divide the surface into two faces. We have here one line, one point, and two faces. Hence, if e be the number of lines, s the number of points, and f the number of faces, then in general

$$e - s - f = m$$

when m remains constant, however many lines be drawn. But in the case of a simple closed surface

$$m = -2 .$$

If the closed surface is doubly connected, like that of a solid body with a hole through it, then if we draw one closed curve round the hole, and another closed curve through the hole, and round one side of the body, we shall have $e = 2$, $s = 1$, $f = 1$, so that $n = 0$. If the surface is n-ly connected, like that of a solid with $n - 1$ holes through it, then we may draw n closed curves round the $n - 1$ holes and the outside of the body, and $n - 1$ other closed curves each through a hole and round the outside of the body.

We shall then have $4(n - 1)$ segments of curves terminating in $2(n - 1)$ points and dividing the surface into two faces, so that $e = 4(n - 1)$, $s = 2\ (n - 1)$, and $f = 2$, and

$$e - s - f = 2n - 4 ,$$

and this is the general relation between the edges, summits, and faces of a polyhedron whose surface is n-ly connected.

The plane reciprocal diagrams, considered as plane projections of such

* See RIEMANN, Crelle's Journal, 1857, *Lehrsätze aus der analysis situs*, for space of two dimensions; also CAYLEY on the Partitions of a Close, Phil. Mag. 1861; HELMHOLTZ, Crelle's Journal, 1858, *Wirbelbewegung*, for the application of the idea of multiple continuity to space of three dimensions; J. B. LISTING, Göttingen Trans., 1861, *Der Census Räumlicher Complexe*, a complete treatise on the subject of Cyclosis and Periphraxy.

On the importance of this subject see GAUSS, Werke, v. 605, "Von der *Geometria Situs* die LEIBNITZ ahnte und in die nur einem Paar Geometern (EULER und VANDERMONDE) einen schwachen Blick zu thun vergönnt war, wissen und haben wir nach anderthalbhundert Jahren noch nicht viel mehr wie nichts."

Note added March 14, 1870.—Since this was written, I have seen LISTING'S *Census*. In his notation, the surface of an n-ly connected body (a body with $n - 1$ holes through it) is $(2n - 2)$ cyclic. If $2n - 2 = K_2$ expresses the degree of cyclosis, then LISTING'S general equation is—

$$s - (e - K_1) + (f - K_2 + \varpi_2) - (v - K_3 + \varpi_3 - w) = 0 ,$$

where s is the number of points, e the number of lines, K_1 the number of endless curves, f the number of faces, K_2 the number of degrees of cyclosis of the faces, ϖ_2 the number of periphractic or closed faces, v the number of regions of space, K_3 their number of degrees of cyclosis, ϖ_3 their number of degrees of periphraxy or the number of regions which they completely surround, and w is to be put $= 1$ or $= 0$, according as the system does or does not extend to infinity.

polyhedra, have the same relation between the numbers of their lines, points, and polygons. It is manifest that since

$$e_1 = e_2 , \qquad s_1 = f_1 , \qquad \text{and } f_1 = s_2 ,$$

where the suffixes refer to the first and second diagrams respectively

$$n_1 = n_2 ,$$

or the two diagrams are connected to the same degree.

On the Degrees of Freedom and Constraint of Frames.

To determine the positions of s points in space, with reference to a given origin and given axes, $3s$ data are required; but since the position of the origin and axes involve 6 data, the number of data required to determine the relative position of s points is $3s - 6$.

If, therefore, the lengths of $3s - 6$ lines joining selected pairs of a system of s points be given, and if these lengths are all independent of each other, then the distances between any other pair of points will be determinate, and the system will be rigidly connected.

If, however, the lines are so chosen that those which join pairs of points of a system of s' of the points are more than $3s' - 6$ in number, the lengths of these lines will not be independent of each other, and the lines of this partial system will only give $3s' - 6$ independent data to determine the complete system.

In a system of s points joined by e lines, there will in general be $3s - 6 - e = p$ degrees of freedom, provided that in every partial system of s' points joined by e' lines, and having in itself p' degrees of freedom, p' is not negative. If in any such system p is negative, we may put $q = -p$, and call q the number of degrees of constraint, and there will be q equations connecting the lengths of the lines; and if the system is a material one, the stress along each piece will be a function of q independent variables. Such a system may be said to have q degrees of constraint. If p' is negative in any partial system, then the degrees of freedom of the complete system are $p - p'$, where p and p' are got from the number of points and lines in the complete and partial systems. If s points are connected by e lines, so as to form a polyhedron of f faces, enclosing a space n times connected, and if each of the faces has m sides, then

$$mf = 2e .$$

We have also

$$e - s - f = 2n - 4 ,$$

and

$$3s - e = p + 6 ,$$

whence

$$p = 6(1 - n) + \left(2 - \frac{6}{m}\right)e$$

If all the faces of the polyhedron are triangles, $m = 3$, and we have

$$p = 6(1 - n) .$$

If $n = 1$, or in the case of a simply connected polyhedron with triangular faces, $p = o$, that is to say, such a figure is a rigid system, which would be no longer rigid if any one of its lines were wanting. In such a figure, if made of material rods forming a closed web of triangles, the tensions and pressures in the rods would be completely determined by the external forces applied to the figure, and if there were no external force, there would be no stress in the rods.

In a closed surface of any kind, if we cover the surface* with a system of curves which do not intersect each other, and if we draw another system intersecting these, and a third system passing diagonally through the intersections of the other two, the whole surface will be covered with small curvilinear triangles, and if we now substitute for the surface a system of rectilinear triangles having the same angular points, we shall have a polyhedron with triangular faces differing infinitely little from the surface, and such that the length of any line on the surface differs infinitely little from that of the corresponding line on the polyhedron. We may, therefore, in all questions about the transformation of surfaces by bending, substitute for them such polyhedra with triangular faces.

We thus find with respect to a simply connected closed inextensible surface —1*st*, That it is of invariable form ;† 2*d*, That the stresses in the surface depend entirely on the external applied forces ;‡ 3*d*, That if there is no external force, there is no stress in the surface.

In the limiting case of the curved surface, however, a kind of deformation is possible, which is not possible in the case of the polyhedron. Let us suppose that in some way a dimple has been formed on a convexo-convex part of the surface, so that the edge of the dimple is a plane closed curve, and the dimpled part is the reflexion in this plane of the original form of the surface. Then the length of any line drawn on the surface will remain unchanged.

Now let the dimple be gradually enlarged, so that its edge continually changes its position. Every line on the surface will still remain of the same length during the whole process, so that the process is possible in the case of an inextensible surface. In this way such a surface may be gradually turned outside in, and since the dimple may be formed from a mere point, a pressure applied at a single point on the outside of an inextensible surface will not be resisted, but will form a dimple which will increase till one part of the surface comes in contact with another.

In the case of closed surfaces doubly connected, $p = -6$, that is, such sur-

* On the Bending of Surfaces, by J. Clerk Maxwell. Cambridge Transactions, 1856.

† This has been shown by Professor Jellett, Trans. R.I.A., vol. xxii. p. 377.

‡ On the Equilibrium of a Spherical Envelope, by J. C. Maxwell. Quarterly Journal of Mathematics, 1867.

faces are not only rigid, but are capable of internal stress, independent of external forces, and the expression of this stress depends on six independent variables.

In a polyhedron with triangular faces, if a number of the edges be taken away so as to form a hole with e_1 sides, the number of degrees of freedom is

$$p = e_1 - 6n + 3 .$$

Hence, in order to make an n-ly connected polyhedron simply rigid without stress, we may cut out the edges till we have formed a hole having $6n - 3$ edges. The system will then be free from stress, but if any more edges be removed, the system will no longer be rigid.

Since in the limiting case of the inextensible surface, the smallest hole may be regarded as having an infinite number of sides, the smallest hole made in a closed inextensible surface connected to any degree will destroy its rigidity. Its flexibility, however, may be confined within very narrow limits.

In the case of a plane frame of s points, we have $2s$ data required to determine the points with reference to a given origin and axes; but since 3 arbitrary data are involved in the choice of origin and axis, the number of data required to determine the relative position of s points in a plane is $2s - 3$.

If we know the lengths of e lines joining certain pairs of these points, then in general the number of degrees of freedom of the frame will be

$$p = 2s - e - 3 .$$

If, however, in any partial system of s' points connected by e' lines, the quantity $p' = 2s' - e' - 3$ be negative, or in other words, if a part of the frame be self-strained, this partial system will contribute only $2s' - 3$ equations independent of each other to the complete system, and the whole frame will have $p - p'$ degrees of freedom.

In a plane frame, consisting of a single sheet, every element of which is triangular, and in which the pieces form three systems of continuous lines, as at p. 11, if the frame contains e pieces connecting s points, s' of which are on the circumference of the frame and s_1 in the interior, then

$$3s - s' = e + 3 .$$

Hence

$$p = -(s - s') = -s_1 ,$$

a negative quantity, or such a frame is necessarily stiff; and if any of the points are in the interior of the frame, the frame has as many degrees of constraint as there are interior points—that is, the stresses in each piece will be functions of s_1 variables, and s_1 pieces may be removed from the frame without rendering it loose.

If there are n holes in the frame, so that s' points lie on the circumference of the frame or on those of the holes, and s_1 points lie in the interior, the degree of stiffness will be

$$-p = s_1 + 3n .$$

If a plane frame be a projection of a polyhedron of f faces, each of m sides, and enclosing a space n times connected, then

$$\begin{aligned} mf &= 2e \\ e - s - f &= 2n - 4 \\ 2s - e &= p + 3 , \end{aligned}$$

whence

$$p = 5 - 4n + \left(1 - \frac{4}{m}\right) e .$$

If all the faces are quadrilaterals $m = 4$ and $p = 5 - 4n$, or a plane frame which is the projection of a closed polyhedron with quadrilateral faces, has one degree of freedom if the polyhedron is simply connected, as in the case of the projection of the solid bounded by six quadrilaterals, but if the polyhedron be doubly connected, the frame formed by its plane projection will have three degrees of stiffness. (See Diagram II.)

Theorem.—If every one of a system of points in a plane is in equilibrium under the action of tensions and pressures acting along the lines joining the points, then if we substitute for each point a small smooth ring through which smooth thin rods of indefinite length corresponding to the lines are compelled to pass, then, if to each rod be applied a couple in the plane, whose moment is equal to the product of the length of the rod between the points multiplied by the tension or pressure in the former case, and tends to turn the rod in the positive or the negative direction, according as the force was a tension or a pressure, then every one of the system of rings will be in equilibrium. For each ring is acted on by a system of forces equal to the tensions and pressures in the former case, each to each, the whole system being turned round a right angle, and therefore the equilibrium of each point is undisturbed.

Theorem.—In any system of points in equilibrium in a plane under the action of repulsions and attractions, the sum of the products of each attraction multiplied by the distance of the points between which it acts, is equal to the sum of the products of the repulsions multiplied each by the distance of the points between which it acts.

For since each point is in equilibrium under the action of a system of attractions and repulsions in one plane, it will remain in equilibrium if the system of forces is turned through a right angle in the positive direction. If this operation is performed on the systems of forces acting on all the points, then at the extremities of each line joining two points we have two equal forces at right

angles to that line and acting in opposite directions, forming a couple whose magnitude is the product of the force between the points and their distance, and whose direction is positive if the force be repulsive, and negative if it be attractive. Now since every point is in equilibrium these two systems of couples are in equilibrium, or the sum of the positive couples is equal to that of the negative couples, which proves the theorem.

In a plane frame, loaded with weights in any manner, and supported by vertical thrusts, each weight must be regarded as attracted towards a horizontal base line, and each support of the frame as repelled from that line. Hence the following rule :—

Multiply each load by the height of the point at which it acts, and each tension by the length of the piece on which it acts, and add all these products together.

Then multiply the vertical pressures on the supports of the frame each by the height at which it acts, and each pressure by the length of the piece on which it acts, and add the products together. This sum will be equal to the former sum.

If the thrusts which support the frame are not vertical, their horizontal components must be treated as tensions or pressures borne by the foundations of the structure, or by the earth itself.

The importance of this theorem to the engineer arises from the circumstance that the strength of a piece is in general proportional to its section, so that if the strength of each piece is proportional to the stress which it has to bear, its weight will be proportional to the product of the stress multiplied by the length of the piece. Hence these sums of products give an estimate of the total quantity of material which must be used in sustaining tension and pressure respectively.

The following method of demonstrating this theorem does not require the consideration of couples, and is applicable to frames in three dimensions.

Let the system of points be caused to contract, always remaining similar to its original form, and with its pieces similarly situated, and let the same forces continue to act upon it during this operation, so that every point is always in equilibrium under the same system of forces, and therefore no work is done by the system of forces as a whole.

Let the contraction proceed till the system is reduced to a point. Then the work done by each tension is equal to the product of that tension by the distance through which it has acted, namely, the original distance between the points. Also the work spent in overcoming each pressure is the product of that pressure by the original distance of the points between which it acts; and since no work is gained or lost on the whole, the sum of the first set of products must be equal to the sum of the second set. In this demonstration it is not necessary

to suppose the points all in one plane. This demonstration is mathematically equivalent to the following algebraical proof :—

Let the co-ordinates of the n different points of the system be $x_1\ y_1\ z_1$, $x_2\ y_2\ z_2$, $x_p\ y_p\ z_p$, &c., and let the force between any two points p, q, be P_{pq}, and their distance r_{pq}, and let it be reckoned positive when it is a pressure, and negative when it is a tension, then the equation of equilibrium of any point p with respect to forces parallel to x is

$$(x_p - x_1)\frac{\mathrm{P}_{p_1}}{r_{p_1}} + (x_p - x_2)\frac{\mathrm{P}_{p_2}}{r_{p_2}} + \&c. + (x_p - x_q)\frac{\mathrm{P}_{pq}}{r_{pq}} + \&c. = 0\,,$$

or generally, giving t all values from 1 to n,

$$\Sigma_1^n{}_t \left\{ (x_p - x_t)\frac{\mathrm{P}_{pt}}{r_{pt}} \right\} = 0\,.$$

Multiply this equation by x_p. There are n such equations, so that if each is multiplied by its proper co-ordinate and the sum taken, we get

$$\Sigma_1^n{}_p\ \Sigma_1^n{}_t \left\{ (x_p - x_t)^2\frac{\mathrm{P}_{pt}}{r_{pt}} \right\} = 0\,,$$

and adding the corresponding equations in y and z, we get

$$\Sigma_1^n{}_p\ \Sigma_1^n{}_t \left(\mathrm{P}_{pt}\ r_{pt} \right) = 0\,,$$

which is the algebraic expression of the theorem.

General Theory of Diagrams of Stress in Three Dimensions.

First Method of Representing Stress in a Body.

Definition.—A diagram of stress is a figure having such a relation to a body under the action of internal forces, that if a surface A, limited by a closed curve, is drawn in the body, and if the corresponding limited surface a be drawn in the diagram of stress, then the resultant of the actual internal forces on the positive side of the surface A in the body is equal and parallel to the resultant of a uniform normal pressure p acting on the positive side of the surface a in the diagram of stress.

Let x, y, z be the co-ordinates of any point in the body, ξ, η, ζ those of the corresponding point in the diagram of stress, then ξ, η, ζ are functions of x, y, z, the nature of which we have to ascertain, so that the internal forces in the body may be in equilibrium. For the present we suppose no external forces, such as gravity, to act on the particles of the body. We shall consider such forces afterwards.

Theorem 1.—If any closed surface is described in the body, and if the stress on any element of that surface is equal and parallel to the pressure on the cor-

responding element of surface in the diagram of stress, then the resultant stress on the whole closed surface will vanish; for the corresponding surface in the diagram of stress is a closed surface, and the resultant of a uniform normal pressure p on every element of a closed surface is zero by hydrostatics.

It does not, however, follow that the portion of the body within the closed surface is in equilibrium, for the stress on its surface may have a resultant moment.

Theorem 2.—To ensure equilibrium of every part of the body, it is necessary and sufficient that

$$\xi = \frac{d\mathrm{F}}{dx} \qquad \eta = \frac{d\mathrm{F}}{dy} \qquad \zeta = \frac{d\mathrm{F}}{dz},$$

where F is any function of x y and z.

Let us consider the elementary area in the body $dy\ dz$. The stress acting on this area will be a force equal and parallel to the resultant of a pressure p acting on the corresponding element of area in the diagram of stress. Resolving this pressure in the directions of the co-ordinate axes, we find the three components of stress on $dy\ dz$, which we may call $p_{xx}\,dy\ dz$, $p_{xy}\,dy\ dz$, and $p_{xz}\,dy\ dz$, each equal to p multiplied by the area of the projection of the corresponding element of the diagram of stress on the three co-ordinate planes. Now, the projection on the plane yz, is

$$\left(\frac{d\eta}{dy}\frac{d\zeta}{dz} - \frac{d\eta}{dz}\frac{d\zeta}{dy}\right) dy\, dz\ .$$

Hence we find for the component of stress in the direction of x

$$p_{xx} = p\left(\frac{d\eta}{dy}\frac{d\zeta}{dz} - \frac{d\eta}{dz}\frac{d\zeta}{dy}\right),$$

which we may write for brevity at present

$$p_{xx} = p\mathrm{J}(\eta\ ,\ \zeta;\ y\ ,z)\ .$$

Similarly,

$$p_{xy} = p\mathrm{J}(\zeta\ ,\ \xi\ ;\ y\ ,z) \qquad p_{xz} = p\mathrm{J}(\xi\ ,\eta\ ;\ y\ ,z)\ .$$

In the same way, we may find the components of stress on the areas $dz\ dx$ and $dx\ dy$—

$$p_{yx} = p\mathrm{J}(\eta\ ,\zeta;\ z\ ,x) \qquad p_{yy} = p\mathrm{J}(\zeta\ ,\xi\ ;\ z\ ,x) \qquad p_{yz} = p\mathrm{J}(\xi\ ,\eta\ ;\ z\ ,x)$$
$$p_{xz} = p\mathrm{J}(\eta\ ,\zeta;\ x\ ,y) \qquad p_{zy} = p\mathrm{J}(\zeta\ ,\xi\ ;\ x\ ,y) \qquad p_{zz} = p\mathrm{J}(\xi\ ,\eta\ ;\ x\ ,y)\ .$$

Now, consider the equilibrium of the parallelopiped $dx\ dy\ dz$, with respect to the moment of the tangential stresses about its axes.

The moments of the forces tending to turn this elementary parallelopiped about the axis of x are

$$dz\ dx\ p_{yz}\ .\ dy - dx\ dy\ p_{zy}\ .\ dz\ .$$

To ensure equilibrium as respects rotation about the axis of x, we must have

$$p_{yz} = p_{zy}\ .$$

Similarly, for the moments about the axes of y and z, we obtain the equations

$$p_{zx} = p_{xz} \quad \text{and} \quad p_{xy} = p_{yx} .$$

Now, let us assume for the present

$$\frac{d\xi}{dx} = A_1 , \qquad \frac{d\xi}{dy} = B_3 + C_3 , \qquad \frac{d\xi}{dz} = B_2 - C_2 ,$$

$$\frac{d\eta}{dx} = B_3 - C_3 , \quad \frac{d\eta}{dy} = A_2 , \qquad \frac{d\eta}{dz} = B_1 + C_1 ,$$

$$\frac{d\zeta}{dx} = B_2 + C_2 , \quad \frac{d\zeta}{dy} = B_1 - C_1 , \qquad \frac{d\zeta}{dz} = A_3 .$$

Then the equation $p_{yz} = p_{zy}$ becomes

$$p\left(\frac{d\xi}{dz}\frac{d\eta}{dx} - \frac{d\xi}{dx}\frac{d\eta}{dz}\right) = p\left(\frac{d\zeta}{dx}\frac{d\xi}{dy} - \frac{d\zeta}{dy}\frac{d\xi}{dx}\right)$$

or

$$(B_2 - C_2)(B_3 - C_3) - A_1(B_1 + C_1) = (B_2 + C_2)(B_3 + C_3) - A_1(B_1 - C_1)$$

$$0 = A_1C_1 + B_3C_2 + B_2C_3 .$$

Similarly, from the two other equations of equilibrium we should find

$$0 = A_2C_2 + B_1C_3 + B_3C_1$$

$$0 = A_3C_3 + B_2C_1 + B_1C_2 .$$

From these three equations it follows that

$$C_1 = 0 \qquad C_2 = 0 \qquad C_3 = 0 .$$

Hence

$$\frac{d\eta}{dz} = \frac{d\zeta}{dy} , \quad \frac{d\zeta}{dx} = \frac{d\xi}{dz} , \quad \frac{d\xi}{dy} = \frac{d\eta}{dx} ,$$

and $\xi dx + \eta dy + \zeta dz$ is a complete differential of some function, F, of x, y and z, whence it follows that

$$\xi = \frac{dF}{dx} , \quad \eta = \frac{dF}{dy} , \quad \zeta = \frac{dF}{dz} .$$

F may be called the function of stress, because when it is known, the diagram of stress may be formed, and the components of stress calculated. The form of the function F is limited only by the conditions to be fulfilled at the bounding surface of the body.

The six components of stress expressed in terms of F are

$$p_{xx} = p\left(\frac{d^2F}{dy^2}\frac{d^2F}{dz^2} - \left(\frac{d^2F}{dydz}\right)^2\right), \quad p_{yy} = p\left(\frac{d^2F}{dz^2}\frac{d^2F}{dx^2} - \left(\frac{d^2F}{dzdx}\right)^2\right), \quad p_{zz} = p\left(\frac{d^2F}{dx^2}\frac{dF^2}{dy^2} - \left(\frac{d^2F}{dxdy}\right)^2\right),$$

$$p_{yz} = p\left(\frac{d^2F}{dzdx}\frac{d^2F}{dxdy} - \frac{d^2F}{dx^2}\frac{d^2F}{dydz}\right), \quad p_{zx} = p\left(\frac{d^2F}{dxdy}\frac{d^2F}{dydz} - \frac{d^2F}{dy^2}\frac{d^2F}{dzdx}\right), \quad p_{xy} = p\left(\frac{d^2F}{dydz}\frac{d^2F}{dzdx} - \frac{d^2F}{dz^2}\frac{d^2F}{dxdy}\right).$$

If $\frac{dF}{dz} = z$, F becomes AIRY's function of stress in two dimensions, and we have

$$p_{xx} = p\frac{d^2F}{dy^2}, \quad p_{yy} = p\frac{d^2F}{dx^2}, \quad p_{xy} = -p\frac{d^2F}{dxdy}.$$

The system of stress in three dimensions deduced in this way from any function, F, satisfies the equations of equilibrium of internal stress. It is not, however, a general solution of these equations, as may be easily seen by taking the case in which p_{xz} and p_{yz} are both zero at all points. In this case, since there is no tangential action in planes parallel to xy, the stresses p_{xx}, p_{xy} and p_{yy} in each stratum must separately fulfil the conditions of equilibrium,

$$\frac{d}{dx}p_{xx} + \frac{d}{dy}p_{xy} = 0, \qquad \frac{d}{dx}p_{xy} + \frac{d}{dy}p_{yy} = 0.$$

The complete solution of these equations is, as we have seen,

$$p_{xx} = \frac{d^2f}{dy^2}, \quad p_{xy} = -\frac{d^2f}{dx\,dy}, \quad p_{yy} = \frac{d^2f}{dx^2},$$

where f is any function of x and y, the form of which may be different for every different value of z, so that we may regard f as a perfectly general function of x y and z.

Again, if we consider a cylindrical portion of the body with its generating lines parallel to z, we shall see that there is no tangential action parallel to z between this cylinder and the rest of the body. Hence the longitudinal stress in this cylinder must be constant throughout its length, and is independent of the stress in any other part of the body.

Hence

$$p_{zz} = \phi(xy),$$

where ϕ is a function of x and y only, but may be any such function. But expressing the stresses in terms of F under the conditions $p_{xz}=0$, $p_{yz}=0$, we find that if F is a perfectly general function of x and y

$$\frac{d^2F}{dx\,dz} = 0 \quad \text{and} \quad \frac{d^2F}{dy\,dz} = 0,$$

whence it follows that $\frac{dF}{dx}$ and $\frac{dF}{dy}$ are functions of x and y only, and that $\frac{dF}{dz}$ is a function of z only. Hence

$$F = G + Z,$$

when G is a function of x and y only, and Z a function of z only, and the components of stress are

$$p_{xx} = p\frac{d^2G}{dy^2}\frac{d^2Z}{dz^2}, \quad p_{yy} = p\frac{d^2G}{dx^2}\frac{d^2Z}{dz^2}, \quad p_{zz} = p\left(\frac{d^2G}{dx^2}\frac{d^2G}{dy^2} - \overline{\frac{d^2G}{dx\,dy}}^2\right)$$

$$p_{yz} = 0, \qquad p_{zx} = 0, \qquad p_{xy} = -p\frac{d^2G}{dx\,dy}\frac{d^2Z}{dz^2}.$$

Here the function f which determines the stress in the strata parallel to xy is

$$f = p\,\mathrm{G}\frac{d^2\mathrm{Z}}{dz^2}.$$

Now, this function is not sufficiently general, for instead of being any function of x, y and z, it is the product of a function of x and y multiplied by a function of z.

Besides this, though the value of p_{zz} is, as it ought to be, a function of x and y only, it is not of the most general form, for it depends on G, the function which determines the stresses p_{xx}, p_{xy}, and p_{yy}, whereas the value of p_{zz} may be entirely independent of the values of these stresses. In fact, the equations give

$$p_{zz} = p\,\frac{p_{xx}p_{yy} - \overline{p_{xy}}^2}{\left(\frac{d^2\mathrm{Z}}{dz^2}\right)^2}.$$

This method, therefore, of representing stress in a body of three dimensions is a restricted solution of the equations of equilibrium.

On Reciprocal Diagrams in Three Dimensions.

Let us consider figures in two portions of space, which we shall call respectively the first and the second diagrams. Let the co-ordinates of any point in the first diagram be denoted by x, y, z, and those of the corresponding point in the second by ξ, η, ζ, measured in directions parallel to x, y, z respectively. Let F be a quantity varying from point to point of the first figure in any continuous manner; that is to say, if A, B are two points, and F_1, F_2 the values of F at those points; then, if B approaches A without limit, the value of F_2 approaches that of F_1 without limit. Let the co-ordinates (ξ, η, ζ) of a point in the second diagram be determined from x, y, z, those of the corresponding point in the first by the equations

$$\xi = \frac{d\mathrm{F}}{dx}\ ,\quad \eta = \frac{d\mathrm{F}}{dy}\ ,\quad \zeta = \frac{d\mathrm{F}}{dz} \qquad . \quad . \quad . \quad . \quad (1).$$

This is equivalent to the statement, that the vector (ρ) of any point in the second diagram represents in direction and magnitude the rate of variation of F at the corresponding point of the first diagram.

Next, let us determine another function, ϕ, from the equation

$$x\xi + y\eta + z\zeta = \mathrm{F} + \phi \qquad . \quad . \quad . \quad . \quad . \quad (2),$$

ϕ, as thus determined, will be a function of x, y, and z, since ξ, η, ζ are known in terms of these quantities. But, for the same reason, ϕ is a function of ξ, η, ζ. Differentiate ϕ with respect to ξ, considering x, y and z functions of ξ, η, ζ,

$$\frac{d\phi}{d\xi} = x + \xi\frac{dx}{d\xi} + \eta\frac{dy}{d\xi} + \zeta\frac{dz}{d\xi} - \frac{d\mathrm{F}}{d\xi}$$

Substituting the values of ξ, η, ζ from (1)

$$\frac{d\phi}{d\xi} = x + \frac{d\mathrm{F}}{dx}\frac{dx}{d\xi} + \frac{d\mathrm{F}}{dy}\frac{dy}{d\xi} + \frac{d\mathrm{F}}{dz}\frac{dz}{d\xi} - \frac{d\mathrm{F}}{d\xi}$$
$$= x + \frac{d\mathrm{F}}{d\xi} - \frac{d\mathrm{F}}{d\xi}$$
$$= x$$

Differentiating ϕ with respect to η and ζ, we get the three equations

$$x = \frac{d\phi}{d\xi} \qquad y = \frac{d\phi}{d\eta} \qquad z = \frac{d\phi}{d\zeta} \quad . \quad . \quad . \quad . \quad (3),$$

or the vector (r) of any point in the first diagram represents in direction and magnitude the rate of increase of ϕ at the corresponding point of the second diagram.

Hence the first diagram may be determined from the second by the same process that the second was determined from the first, and the two diagrams, each with its own function, are reciprocal to each other.

The relation (2) between the functions expresses that the sum of the functions for two corresponding points is equal to the product of the distances of these points from the origin multiplied by the cosine of the angle between the directions of these distances.

Both these functions must be of two dimensions in space. Let F′ be a linear function of xyz, which has the same value and rate of variation as F has at the point $x_0\ y_0\ z_0$

$$\mathrm{F}' = \mathrm{F}_0 + (x - x_0)\frac{d\mathrm{F}_0}{dx} + (y - y_0)\frac{d\mathrm{F}_0}{dy} + (z - z_0)\frac{d\mathrm{F}_0}{dz} \quad . \quad . \quad (4).$$

The value of F′ at the origin is found by putting x, y and $z = 0$

$$\mathrm{F}' = \mathrm{F}_0 - x_0\xi - y_0\eta - z_0\zeta = -\phi \quad . \quad . \quad . \quad . \quad (5),$$

or the value of F′ at the origin is equal and opposite to the value of ϕ at the point ξ, η, ζ.

If the rate of variation of F is nowhere infinite, the co-ordinates $\xi\ \eta\ \zeta$ of the second diagram must be everywhere finite, and *vice versa*. Beyond the limits of the second diagram the values of x, y, z, in terms of ξ, η, ζ, must be impossible, and therefore the value of ϕ is also impossible. Within the limits of the second diagram, the function ϕ has an even number of values at every point, corresponding to an even number of points in the first diagram, which correspond to a single point in the second.

To find these points in the first diagram, let ρ be the vector of a given point in the second diagram, and let surfaces be drawn in the first diagram for which F is constant, and let points be found in each of these surfaces at which the tangent plane is perpendicular to ρ, these points will form one or more curves, which must be either closed or infinite, and the points on these curves corres-

pond to the points in the second diagram which lie in the direction of the vector ρ. If p be the perpendicular from a point in the first diagram on a plane through the origin perpendicular to ρ, then all those points on these curves at which $\frac{d\mathrm{F}}{dp} = \rho$ correspond to the given point in the second diagram. Now, since this point is within the second diagram, there are values of ρ both greater and less than the given one; and therefore $\frac{d\mathrm{F}}{dp}$ is neither an absolute maximum nor an absolute minimum value. Hence there are in general an even number of points on the curve or curves which correspond to the given point. Some of these points may coincide, but at least two of them must be different, unless the given point is at the limit of the second diagram.

Let us now consider the two reciprocal diagrams with their functions, and ascertain in what the geometrical nature of their reciprocity consists.

(1.) Let the first diagram be simply the point P_1, (x_1, y_1, z_1), at which $\mathrm{F} = \mathrm{F}_1$, then in the other diagram

$$\phi = x_1\xi + y_1\eta + z_1\zeta - \mathrm{F}_1 \quad . \quad . \quad . \quad . \quad . \quad (6),$$

or a point in one diagram is reciprocal to a space in the other, in which the function ϕ is a linear function of the co-ordinates.

(2.) Let the first diagram contain a second point P_2, (x_2, y_2, z_2) at which $\mathrm{F} = \mathrm{F}_2$, then we must combine equation (6) with

$$\phi = x_2\xi + y_2\eta + z_2\zeta - \mathrm{F}_2 \quad . \quad . \quad . \quad . \quad (7),$$

whence eliminating ϕ,

$$(x_1 - x_2)\xi + (y_1 - y_2)\eta + (z_1 - z_2)\zeta = \mathrm{F}_1 - \mathrm{F}_2 .$$

If r_{12} is the length of the line drawn from the first point P_1 to the second P_2; and if $l_{12}\, m_{12}\, n_{12}$ are its direction cosines, this equation becomes

$$l_{12}\xi + m_{12}\eta + n_{12}\zeta = \frac{\mathrm{F}_2 - \mathrm{F}_1}{r_{12}},$$

or the reciprocal of the two points P_1 and P_2 is a plane, perpendicular to the line joining them, and such that the perpendicular from the origin on the plane multiplied by the length of the line $\mathrm{P}_1\mathrm{P}_2$ is equal to the excess of F_2 over F_1.

(3.) Let there be a third point P_3 in the first diagram, whose co-ordinates are $x_3\, y_3\, z_3$ and for which $\mathrm{F} = \mathrm{F}_3$; then we must combine with equations (6) and (7)

$$\phi = x_3\xi + y_3\eta + z_3\zeta - \mathrm{F}_3 \quad . \quad . \quad . \quad . \quad (8).$$

The reciprocal of the three points $\mathrm{P}_1\, \mathrm{P}_2\, \mathrm{P}_3$ is a straight line perpendicular to the plane of the three points, and such that the perpendicular on this line from the origin represents, in direction and magnitude, the rate of most rapid increase of F in the plane $\mathrm{P}_1\, \mathrm{P}_2\, \mathrm{P}_3$, F being a linear function of the co-ordinates whose values at the three points are those given.

(4.) Let there be a fourth point P_4 for which $F = F_4$.

The reciprocal of the four points is a single point, and the line drawn from the origin to this point represents, in direction and magnitude, the rate of greatest increase of F, supposing F such a linear function of xyz that its values at the four points are those given. The value of ϕ at this point is that of F at the origin.

Let us next suppose that the value of F is continuous, that is, that F does not vary by a finite quantity when the co-ordinates vary by infinitesimal quantities, but that the form of the function F is discontinuous, being a different linear function of xyz in different parts of space, bounded by definite surfaces.

The bounding surfaces of these parts of space must be composed of planes. For let the linear functions of xyz in contiguous portions of space be

$$F_1 = \alpha_1 x + \beta_1 y + \gamma_1 z - \phi_1$$
$$F_2 = \alpha_2 x + \beta_2 y + \gamma_2 z - \phi_2,$$

then at the bounding surface, where $F_1 = F_2$

$$(\alpha_1 - \alpha_2)x + (\beta_1 - \beta_2)\gamma + (\gamma_1 - \gamma_2)z = \phi_1 - \phi_2 \quad . \quad . \quad . \quad (9),$$

and this is the equation of a plane.

Hence the portion of space in which any particular form of the value of F holds good must be a polyhedron or cell bounded by plane faces, and therefore having straight edges meeting in a number of points or summits.

Every face is the boundary of two cells, every edge belongs to three or more cells, and to two faces of each cell.

Every summit belongs to at least four cells, to at least three faces of each cell, and to two edges of each face.

The whole space occupied by the diagram is divided into cells in two different ways, so that every point in it belongs to two different cells, and has two values of F and its derivatives.

The reciprocal diagram is made up of cells in the same way, and the reciprocity of the two diagrams may be thus stated:—

1. Every summit in one diagram corresponds to a cell in the other.

The radius vector of the summit represents the rate of increase of the function within the cell, both in direction and magnitude.

The value of the function at the summit is equal and opposite to the value which the function in the cell would have if it were continued under the same algebraical form to the origin.

2. Every edge in the one diagram corresponds to a plane face in the other, which is the face of contact of the two cells corresponding to the two extremities of the edge.

The edge in the one diagram is perpendicular to the face in the other.

The distance of the plane from the origin represents the rate of increase of the function along the edge.

3. Every face in the one diagram corresponds to an edge in which as many cells meet as there are angles in the face, that is, at least three. Every face must belong to two, and only two cells, because the edge to which it corresponds has two, and only two extremities.

4. Every cell in the one diagram corresponds to a summit in the other. Every face of the cell corresponds and is perpendicular to an edge having an extremity in the summit. Since every cell must have four or more faces, every summit must have four or more edges meeting there.

Every edge of the cell corresponds to a face having an angle in the summit. Since every cell has at least six edges, every summit must be the point of concourse of at least six faces, which are the boundaries of cells.

Every summit of the cell corresponds to a cell having a solid angle at the summit. Since every cell has at least four summits, every summit must be the meeting place of at least four cells.

Mechanical Reciprocity of the Diagrams.

If along each of the edges meeting in a summit forces are applied proportional to the areas of the corresponding faces of the cell in the reciprocal diagram, and in a direction which is always inward with respect to the cell, then these forces will be in equilibrium at the summit.

This is the "Polyhedron of Forces," and may be proved by hydrostatics.

If the faces of the cell form a single closed surface which does not intersect itself, it is easy to understand what is meant by the inside and outside of the cell; but if the surface intersects itself, it is better to speak of the positive and negative sides of the surface. A cell, or portion of a cell, bounded by a closed surface, of which the positive side is inward, may be called a positive cell. If the surface intersects itself, and encloses another portion of space with its negative side inward, that portion of space forms a negative cell. If any portion of space is surrounded by n sheets of the surface of the same cell with their positive side inward, and by m sheets with their negative side inward, the space enclosed in this way must be reckoned $n - m$ times.

In passing to a contiguous cell, we must suppose that its face in contact with the first cell has its positive surface on the opposite side from that of the first cell. In this way, by making the positive side of the surface continuous throughout each cell, and by changing it when we pass to the next cell, we may settle the positive and negative side of every face of every cell, the sign of every face depending on which of the two cells it is considered for the moment to belong to.

If we now suppose forces of tension or pressure applied along every edge of the first diagram, so that the force on each extremity of the edge is in the direction of the positive normal to the corresponding face of the cell corresponding to that extremity, and proportional to the area of the face, then these pressures and tensions along the edges will keep every point of the diagram in equilibrium.

Another way of determining the nature of the force along any edge of the first diagram, is as follows:—

Round any edge of the first diagram draw a closed curve, embracing it and no other edge. However small the curve is, it will enter each of the cells which meet in the edge. Hence the reciprocal of this closed curve will be a plane polygon whose angles are the points reciprocal to these cells taken in order. The area of this polygon represents, both in direction and magnitude, the whole force acting through the closed curve, that is, in this case the stress along the edge. If, therefore, in going round the angles of the polygon, we travel in the same direction of rotation in space as in going round the closed curve, the stress along the edge will be a pressure; but if the direction is opposite, the stress will be a tension.

This method of expressing stresses in three dimensions comprehends all cases in which RANKINE's reciprocal figures are possible, and is applicable to certain cases of continuous stress. That it is not applicable to all such cases is easily seen by the example of p (18).

On Reciprocal Diagrams in Two Dimensions.

If we make F a function of x and y only, all the properties already deduced for figures in three dimensions will be true in two; but we may form a more distinct geometrical conception of the theory by substituting cz for F and $c\zeta$ for ϕ. We have then for the equations of relation between the two diagrams

$$\left.\begin{aligned} \xi &= c\frac{dz}{dx} & \eta &= c\frac{dz}{dy} \\ x &= c\frac{d\zeta}{d\xi} & y &= c\frac{d\zeta}{d\eta} \\ x\xi &+ y\eta = cz + c\zeta\,. \end{aligned}\right\} \quad . \quad . \quad (10).$$

These equations are equivalent to the following definitions:—

Let z in the first diagram be given as a function of x and y, z will lie on a surface of some kind. Let x_0, y_0 be particular values of x and y, and let z_0 be the corresponding value of z. Draw a tangent plane to the surface at the point x_0, y_0, z_0, and from the point $\xi = 0, \eta = 0, \zeta = -c$; in the second diagram draw a normal to this tangent plane. It will cut the plane $\zeta = 0$ at the point ξ, η corresponding to xy, and the value of ζ is equal and opposite to the segment of the

axis of z cut off by the tangent plane. The two surfaces may be defined as reciprocally polar (in the ordinary sense) with respect to the paraboloid of revolution

$$x^2 + y^2 = 2cz \quad . \quad . \quad . \quad . \quad . \quad . \quad (11),$$

and the diagrams are the projections on the planes of xy and $\xi\eta$ of points and lines on these surfaces.

If one of the surfaces is a plane-faced polyhedron, the other will also be a plane-faced polyhedron, every face in the one corresponding to a point in the other, and every edge in the one corresponding to the line joining the points corresponding to the faces bounded by the edge. In the projected diagrams every line is perpendicular to the corresponding line, and lines which meet in a point in one figure form a closed polygon in the other.

These are the conditions of reciprocity mentioned at p. 8, and it now appears that if either of the diagrams is a projection of a plane-faced polyhedron, the other diagram can be drawn. If the first diagram cannot be a projection of a plane-faced polyhedron, let it be a projection of a polyhedron whose faces are polygons not in one plane. These faces must be conceived to be filled up by surfaces, which are either curved or made up of different plane portions. In the first case the polygon will correspond not to a point, but to a finite portion of a surface; in the second, it will correspond to several points, so that the lines, which correspond to the edges of such a polygon, will terminate in several points, and not in one, as is necessary for reciprocity.

Second Method of representing Stress in a Body.

Let a, b be any two consecutive points in the first diagram, distant s, and α, β the corresponding points in the second, distant σ, then if the direction cosines of the line $a\ b$ are l, m, n and those of $\alpha\ \beta$, λ, μ, ν

$$\left.\begin{aligned} \sigma\lambda &= sl\frac{d\xi}{dx} + sm\frac{d\xi}{dy} + sn\frac{d\xi}{dz} \\ \sigma\mu &= sl\frac{d\eta}{dx} + sm\frac{d\eta}{dy} + sn\frac{d\eta}{dz} \\ \sigma\nu &= sl\frac{d\zeta}{dx} + sm\frac{d\zeta}{dy} + sn\frac{d\zeta}{dz} \end{aligned}\right\} \quad . \quad . \quad . \quad (12).$$

Hence

$$\frac{\sigma}{s}\left(l\lambda + m\mu + n\nu\right) = l^2\frac{d\xi}{dx} + m^2\frac{d\eta}{dy} + n^2\frac{d\zeta}{dz} + mn\left(\frac{d\eta}{dz} + \frac{d\zeta}{dy}\right) + nl\left(\frac{d\zeta}{dx} + \frac{d\xi}{dz}\right) + lm\left(\frac{d\xi}{dy} + \frac{d\eta}{dx}\right) \quad (13).$$

If we put $l\lambda + m\mu + n\nu = \cos\epsilon$, where ϵ is the angle between s and σ, and if we take three sets of values of $l\,m\,n$, corresponding to three directions at right angles to each other, we find

$$\frac{\sigma_1}{s_1}\cos\epsilon_1 + \frac{\sigma_2}{s_2}\cos\epsilon_2 + \frac{\sigma_3}{s_3}\cos\epsilon_3 = \frac{d\xi}{dx} + \frac{d\eta}{dy} + \frac{d\zeta}{dz} = \frac{d^2\mathrm{F}}{dx^2} + \frac{d^2\mathrm{F}}{dy^2} + \frac{d^2\mathrm{F}}{dz^2} \quad (14).$$

Hence this quantity depends only on the position of the point, and not on the directions of s_1 s_2 s_3 or of x y z, let us call it $\Delta^2 F$.

Now, let us take an element of area perpendicular to s, and let us suppose that the stress on this element is compounded of a normal pressure $= p\Delta^2 F$, and a tension parallel to σ and equal to $p\frac{\sigma}{s}$.

By the rules for the composition of stress, we have for the components of the force on this element, in terms of the six components of stress,

$$\left.\begin{aligned} X &= lp_{xx} + mp_{xy} + np_{xz} = p\left(l\Delta^2 F - \lambda\frac{\sigma}{s}\right) \\ Y &= lp_{xy} + mp_{yy} + np_{yz} = p\left(m\Delta^2 F - \mu\frac{\sigma}{s}\right) \\ Z &= lp_{xz} + mp_{yz} + np_{zz} = p\left(n\Delta^2 F - \nu\frac{\sigma}{s}\right) \end{aligned}\right\} \quad . \quad . \quad (15).$$

Hence,

$$\left.\begin{aligned} &p_{xx} = p\left(\Delta^2 F - \frac{d\xi}{dx}\right) \quad = p\left(\Delta^2 F - \frac{d^2 F}{dx^2}\right) \quad = p\left(\frac{d^2 F}{dy^2} + \frac{d^2 F}{dz^2}\right) \\ &p_{xx} = p\left(\frac{d^2 F}{dy^2} + \frac{d^2 F}{dz^2}\right), p_{yy} = p\left(\frac{d^2 F}{dz^2} + \frac{d^2 F}{dx^2}\right), p_{zz} = p\left(\frac{d^2 F}{dx^2} + \frac{d^2 F}{dy^2}\right) \\ &p_{yz} = -p\frac{d^2 F}{dxdy}, \qquad p_{zx} = -p\frac{d^2 F}{dzdx}, \qquad p_{xy} p = -\frac{d^2 F}{dxdy} \end{aligned}\right\} \quad (16).$$

By substituting these values in the equations of equilibrium

$$\frac{dp_{xx}}{dx} + \frac{dp_{xy}}{dy} + \frac{dp_{xz}}{dz} = 0, \text{ \&c.} \quad . \quad . \quad . \quad . \quad (17),$$

it is manifest that they are fulfilled for any value of F.

The most general solution of these equations of equilibrium is contained in the values

$$\left.\begin{aligned} &p_{xx} = \frac{d^2 B}{dz^2} + \frac{d^2 C}{dy^2} \quad p_{yy} = \frac{d^2 C}{dx^2} + \frac{d^2 A}{dz^2} \quad p_{zz} = \frac{d^2 A}{dy^2} + \frac{d^2 B}{dx^2} \\ &p_{yz} = -\frac{d^2 A}{dydz} \qquad p_{zx} = -\frac{d^2 B}{dzdx} \qquad p_{xy} = -\frac{d^2 C}{dxdy} \end{aligned}\right\} \quad (18).$$

By making $A = B = C = pF$ we get a case which, though restricted in its generality, has remarkable properties with respect to diagrams of stress. We have seen that a distribution of stress according to the definition above (16), is consistent with itself, and will keep a body in equilibrium. Since the stresses are linear functions of F, any two systems of stress can be compounded by adding their respective functions, a process not applicable to the first method of representation by areas.

Let us ascertain what kind of stress is represented in this way in the case of the system of cells already considered.

Since F in each cell is a linear function of x, y, z, there can be no stress at any

point within it. Let us take a and b two contiguous points in different cells, then α and β will be the points at a finite distance to which these cells are reciprocal, and $\Delta^2 F = \frac{a\beta}{ab}$, which becomes infinite when ab vanishes.

If a and b are in the surface bounding the cells, α and β coincide. Hence there is a stress in this surface, uniform in all directions in the plane of the surface, and such that the stress across unit of length drawn on the surface is proportional to the distance between the points which are reciprocal to the two cells bounded by the surface, and this stress is a tension or a pressure according as the two points are similarly or oppositely situated to the two cells.

The kind of equilibrium corresponding to this case is therefore that of a system of liquid films, each having a tension like that of a soap bubble, depending on the nature of the fluid of which it is composed. If all the films are composed of the same fluid, their tensions must be equal, and all the edges of the reciprocal diagram must be equal.

On Airy's *Function of Stress.*

Mr Airy, in a paper "On the Strains in the Interior of Beams,"* was, I believe, the first to point out that, in any body in equilibrium under the action of internal stress in two dimensions, the three components of the stress in any two rectangular directions are the three second derivatives, with respect to these directions, of a certain function of the position of a point in the body.

This important simplification of the theory of the equilibrium of stress in two dimensions does not depend on any theory of elasticity, or on the mode in which stress arises in the body, but solely on the two conditions of equilibrium of an element of a body acted on only by internal stress

$$\frac{d}{dx}p_{xx} + \frac{d}{dy}p_{xy} = 0 \quad \text{and} \quad \frac{d}{dx}p_{xy} + \frac{d}{dy}p_{yy} = 0 \qquad . \quad . \quad (19),$$

whence it follows that

$$p_{xx} = \frac{d^2F}{dy^2} \quad p_{xy} = -\frac{d^2F}{dxdy} \quad \text{and} \quad p_{yy} = \frac{d^2F}{dx^2} \qquad . \quad . \quad . \quad (20),$$

where F is a function of x and y, the form of which is (as far as these equations are concerned) perfectly arbitrary, and the value of which at any point is independent of the choice of axes of co-ordinates. Since the stresses depend on the second derivatives of F, any linear function of x and y may be added to F without affecting the value of the stresses deduced from F. Also, since the stresses are linear functions of F, any two systems of stress may be mechanically compounded by adding the corresponding values of F.

The importance of Airy's function in the theory of stress becomes even more

* Phil. Trans. 1863.

manifest when we deduce from it the diagram of stress, the co-ordinates of whose points are

$$\xi = \frac{d\mathrm{F}}{dy} \quad \text{and} \quad \eta = -\frac{d\mathrm{F}}{dx} \quad . \quad . \quad . \quad . \quad . \quad (21).$$

For if s be the length of any curve in the original figure, and σ that of the corresponding curve in the diagram of stress, and if $\mathrm{X}ds$, $\mathrm{Y}ds$ are the components of the whole stress acting on the element ds towards the right hand of the curve s

$$\left.\begin{aligned} \mathrm{X}ds &= p_{xx}\frac{dy}{ds}ds = \frac{d^2\mathrm{F}}{dy^2}\frac{dy}{ds}ds = \frac{d\xi}{dy}\frac{dy}{dx}ds = \frac{d\xi}{d\sigma}d\sigma \\ \text{and} \qquad \mathrm{Y}ds &= -p_{yy}\frac{dx}{ds}ds = -\frac{d^2\mathrm{F}}{dx^2}\frac{dx}{ds}ds = \frac{dy}{dx}\frac{dx}{ds}ds = \frac{dy}{d\sigma}d\sigma \end{aligned}\right\} \quad (22).$$

Hence the stress on the right hand side of the element ds of the original curve is represented, both in direction and magnitude, by the corresponding element $d\sigma$ of the curve in the diagram of stress, and, by composition, the resultant stress on any finite arc of the first curve s is represented in direction and magnitude by the straight line drawn from the beginning to the end of the corresponding curve σ.

If P_1, P_2 are the principal stresses at any point, and if P_1 is inclined α to the axis of x, then the component stresses are

$$\left.\begin{aligned} p_{xx} &= \mathrm{P}_1\cos^2\alpha + \mathrm{P}_2\sin^2\alpha \\ p_{xy} &= (\mathrm{P}_1 - \mathrm{P}_2)\sin\alpha\cos\alpha \\ p_{yy} &= \mathrm{P}_1\sin^2\alpha + \mathrm{P}_2\cos^2\alpha \end{aligned}\right\} \quad . \quad . \quad (23).$$

Hence

$$\left.\begin{aligned} \tan 2\alpha &= \frac{p_{xy}}{p_{xx} - p_{yy}} = \frac{\dfrac{d^2\mathrm{F}}{dxdy}}{\dfrac{d^2\mathrm{F}}{dx^2} - \dfrac{d^2\mathrm{F}}{dy^2}} \\ \mathrm{P}_1 + \mathrm{P}_2 &= p_{xx} + p_{yy} = \frac{d^2\mathrm{F}}{dx^2} + \frac{d^2\mathrm{F}}{dy^2} \\ \mathrm{P}_1\mathrm{P}_2 &= p_{xx}p_{yy} - p_{xy}^2 = \frac{d^2\mathrm{F}}{dx^2}\frac{d^2\mathrm{F}}{dy^2} - \frac{d^2\mathrm{F}^2}{dxdy} \end{aligned}\right\} \quad . \quad . \quad (24).$$

Consider the area bounded by a closed curve s, and let us determine the surface integral of the sum of the principal stresses over the area within the curve. The integral is

$$\iint(\mathrm{P}_1 + \mathrm{P}_2)\,dxdy = \iint\left(\frac{d^2\mathrm{F}}{dx^2} + \frac{d^2\mathrm{F}}{dy^2}\right)dxdy \quad . \quad . \quad . \quad (25).$$

By a well-known theorem, corresponding in two dimensions to that of GREEN in three dimensions, the latter expression becomes, when once integrated,

$$\int\left(\frac{d\mathrm{F}}{dy}\frac{dx}{ds} - \frac{d\mathrm{F}}{dx}\frac{dy}{ds}\right)ds \quad . \quad . \quad . \quad . \quad . \quad (26),$$

or
$$\int\left(\xi\frac{dx}{ds} + \eta\frac{dy}{ds}\right)ds \quad . \quad . \quad . \quad . \quad . \quad (27).$$

These line integrals are to be taken round the closed curve s. If we take a point in the curve s as origin in the original body, and the corresponding point in σ as origin in the diagram of stress, then ξ and η are the components of the whole stress on the right hand of the curve from the origin to a given point. If ρ denote the line joining the origin with the point $\xi\eta$, then ρ will represent in direction and magnitude the whole stress on the arc σ.

The line integral may now be interpreted as the work done on a point which travels once round the closed curve s, and is everywhere acted on by a force represented in direction and magnitude by ρ. We may express this quantity in terms of the stress at every point of the curve, instead of the resultant stress on the whole arc, as follows :—

For integrating (27) by parts it becomes,
$$-\int\left(x\frac{d\xi}{ds} + y\frac{dy}{ds}\right)ds = -\int(\mathrm{X}x + \mathrm{Y}y)\,ds \quad . \quad . \quad (28),$$

or if $\mathrm{R}ds$ is the actual stress on ds, and r is the radius vector of ds, and if R makes with r an angle ϵ, we obtain the result
$$\iint(\mathrm{P}_1 + \mathrm{P}_2)dxdy = -\int \mathrm{R}r\cos\epsilon.ds\,. \quad . \quad . \quad . \quad . \quad (29).$$

This line integral, therefore, which depends only on the stress acting on the closed curve s, is equal to the surface integral of the sum of the principal stresses taken over the whole area within the curve.

If there is no stress on the curve s acting from without, then the surface integral vanishes. This is the extension to the case of continuous stress of the theorem, given at p. 13, that the algebraic sum of all the tensions multiplied each by the length of the piece in which it acts is zero for a system in equilibrium. In the case of a frame, the stress in each piece is longitudinal, and the whole pressure or tension of the piece is equal to the longitudinal stress multiplied by the section, so that the integral $\iint(\mathrm{P}_1 + \mathrm{P}_2)dxdy$ for each piece is its tension multiplied by its length.

If the closed curve s is a small circle, the corresponding curve σ will be an ellipse, and the stress on any diameter of the circle will be represented in direction and magnitude by the corresponding diameter of the ellipse. Hence, the principal axes of the ellipse represent in direction and magnitude the principal stresses at the centre of the circle.

Let us next consider the surface integral of the product of the principal stresses at every point taken over the area within the closed curve s.
$$\iint \mathrm{P}_1\mathrm{P}_2 dxdy = \iint\left(\frac{d^2\mathrm{F}}{dx^2}\frac{d^2\mathrm{F}}{dy^2} - \overline{\frac{d^2\mathrm{F}}{dxdy}}^2\right)dxdy \quad . \quad . \quad . \quad (30),$$
$$= \iint\left(\frac{d\xi}{dx}\frac{d\eta}{dy} - \frac{d\xi}{dy}\frac{d\eta}{dx}\right)dxdy\,,$$

or by transformation of variables

$$= \iint d\xi d\eta \,.$$

Hence the surface integral of the product of the principal stresses within the curve is equal to the area of the corresponding curve σ in the diagram of stress, and therefore depends entirely on the external stress on the curve s. This is seen from the construction of the curve σ in the diagram of stress, since each element $d\sigma$ represents the stress on the corresponding element ds of the original curve.

If ρ represents in direction and magnitude the resultant of the stress on the curve s from the origin to a point which moves round the curve, then the area traced out by ρ is equal to the surface-integral required. If $\mathrm{X}ds$ and $\mathrm{Y}ds$ are the components of the stress on the element ds, and l the whole length of the closed curve s, then the surface integral is equal to either of the quantities.

$$\int_0^l \mathrm{Y} \int_0^s \mathrm{X} ds \,.\, ds \,, \text{ or } -\int_0^l \mathrm{X} \int_0^s \mathrm{Y} ds \,.\, ds \,.$$

In a frame the stress in each piece is entirely longitudinal, so that the product of the principal stresses is zero, and therefore nothing is contributed to the surface integral except at the points where the pieces meet or cross each other. To find the value of the integral for any one of these points, draw a closed curve surrounding it and no other point, and therefore cutting all the pieces which meet in that point in order. The corresponding figure in the diagram of stress will be a polygon, whose sides represent in magnitude and direction the tensions in the several pieces *taken in order*. The area of this polygon, therefore, represents the value of $\iint \mathrm{P}_1\mathrm{P}_2 dxdy$ for the point of concourse, and is to be considered positive or negative, according as the tracing point travels round it in the positive or the negative cyclical direction.

Hence the following theorem, which is applicable to all plane frames, whether a diagram of forces can be drawn or not.

For each point of concourse or of intersection construct a polygon, by drawing in succession lines parallel and proportional to the forces acting on the point in the several pieces which meet in that point, taking the pieces in cyclical order round the point. The area of this polygon is to be taken positive or negative, according as it lies on the left or the right of the tracing point.

If, then, a closed curve be drawn surrounding the entire frame, and a polygon be drawn by drawing in succession lines parallel and proportional to all the external forces which act on the frame in the order in which their lines of direction meet the closed curve, then the area of this polygon is equal to the algebraic sum of the areas of the polygons corresponding to the various points of the frame.

In this theorem a polygon is to be drawn for every point, whether the lines of the frame meet or intersect, whether they are really jointed together, or whether two pieces simply cross each other without mechanical connection. In the latter case the polygon is a parallelogram, whose sides are parallel and proportional to the stresses in the two pieces, and it is positive or negative according as these stresses are of the same or of opposite signs.

If three or more pieces intersect, it is manifestly the same whether they intersect at one point or not, so that we have the following theorem :—

The area of a polygon of an even number of sides, whose opposite sides are equal and parallel, is equal to the sum of the areas of all the different parallelograms which can be formed with their sides parallel and equal to those of the polygon.

This is easily shown by dividing the polygon into the different parallelograms.

On the Equilibrium of Stress in a Solid Body.

Let PQR be the longitudinal, and STU the tangential components of stress, as indicated in the following table of stresses and strains, taken from THOMSON and TAIT'S "Natural Philosophy," p. 511, § 669 :—

Components of the		Planes, of which Relative Motion, or across which Force, is reckoned.	Direction of Relative Motion or of Force.
Strain.	Stress.		
e	P	yz	x
f	Q	zx	y
g	R	xy	z
a	S	yx zx	y z
b	T	zy xy	z x
c	U	xz yz	x y

Then the equations of equilibrium of an element of the body are, by § 697 of that work,

$$\left.\begin{aligned} \frac{d\mathrm{P}}{dx} + \frac{d\mathrm{U}}{dy} + \frac{d\mathrm{T}}{dz} + \mathrm{X} = 0 \\ \frac{d\mathrm{U}}{dx} + \frac{d\mathrm{Q}}{dy} + \frac{d\mathrm{S}}{dz} + \mathrm{Y} = 0 \\ \frac{d\mathrm{T}}{dx} + \frac{d\mathrm{S}}{dy} + \frac{d\mathrm{R}}{dz} + \mathrm{Z} - 0 \end{aligned}\right\} \quad . \quad . \quad . \quad (1),$$

If we assume three functions ABC, such that

$$\left.\begin{aligned} S &= -\frac{d^2A}{dydz} & T &= -\frac{d^2B}{dzdx} & U &= -\frac{d^2C}{dxdy} \\ \text{and put} \\ X &= \frac{dV}{dx} & Y &= \frac{dV}{dy} & Z &= \frac{dV}{dz} \end{aligned}\right\} \quad . \quad (2),$$

then a sufficiently general solution of the equations of equilibrium is given by putting

$$\left.\begin{aligned} P &= \frac{d^2B}{dz^2} + \frac{d^2C}{dy^2} - V \\ Q &= \frac{d^2C}{dx^2} + \frac{d^2A}{dz^2} - V \\ R &= \frac{d^2A}{dy^2} + \frac{d^2B}{dx^2} - V \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (3),$$

I am not aware of any method of finding other relations between the components of stress without making further assumptions. The most natural assumption to make is that the stress arises from elasticity in the body. I shall confine myself to the case of an isotropic body, such that it can be deprived of all stress and strain by a removal of the applied forces. In this case, if $\alpha\,\beta\,\gamma$ are the components of displacement, and n the co-efficient of rigidity, the equations of tangential elasticity are, by equation (6) §§ 670 and 694 of Thomson and Tait,

$$a = \frac{d\beta}{dz} + \frac{d\gamma}{dy} = \frac{1}{n}S = -\frac{1}{n}\frac{d^2A}{dydz} \quad . \quad . \quad . \quad . \quad (4),$$

with similar equations for b and c. A sufficiently general solution of these equations is given by putting

$$\left.\begin{aligned} a &= \frac{1}{2n}\frac{d}{dx}\left(A - B - C\right) \\ \beta &= \frac{1}{2n}\frac{d}{dy}\left(B - C - A\right) \\ \gamma &= \frac{1}{2n}\frac{d}{dz}\left(C - A - B\right) \end{aligned}\right\} \quad . \quad . \quad . \quad (5).$$

The equations of longitudinal elasticity are of the form given in § 693,

$$P = \left(k + \frac{4}{3}n\right)\frac{da}{dx} + \left(k - \frac{2}{3}n\right)\left(\frac{d\beta}{dy} + \frac{d\gamma}{dz}\right) \quad . \quad . \quad . \quad (6),$$

where k is the co-efficient of cubical elasticity, with similar equations for Q and R. Substituting for P, α, β and γ in equation (6) their values from (3) and (5),

$$2n\left(\frac{d^2B}{dz^2} + \frac{d^2C}{dy^2} - V\right) = \left(k + \frac{4}{3}n\right)\left(\frac{d^2A}{dx^2} - \frac{d^2B}{dx^2} - \frac{d^2C}{dx^2}\right) + \left(k - \frac{2}{3}n\right)\left(\frac{d^2B}{dy^2} - \frac{d^2C}{dy^2} - \frac{d^2A}{dy^2} + \frac{d^2C}{dz^2} - \frac{d^2A}{dz^2} - \frac{d^2B}{dz^2}\right).$$

If we put

$$\frac{d^2A}{dx^2} + \frac{d^2B}{dy^2} + \frac{d^2C}{dz^2} = p, \text{ and } \frac{d^2}{dx^2} + \frac{d^2}{dy^2} + \frac{d^2}{dz^2} = \Delta^2 ,$$

this equation becomes

$$\left(k + \frac{4}{3}n\right)\left(\Delta^2A + \Delta^2B + \Delta^2C\right) - \left(k + \frac{1}{3}n\right)2p - 2nV = 2n\Delta^2A, \quad . \quad (7).$$

We have also two other equations differing from this only in having B and C instead of A on the right hand side. Hence equating the three expressions on the right hand side we find

$$\Delta^2A = \Delta^2B = \Delta^2C = D^2, \text{ say}, \quad . \quad . \quad . \quad . \quad (8),$$

$$(3k + n)2p = (3k + 2n)3D^2 - 2nV, \quad . \quad . \quad . \quad . \quad (9),$$

and

$$P + Q + R = \frac{9k}{2}\frac{D^2 - 2V}{3k + n} = 3k\frac{p - 3V}{3k + 2n} \quad . \quad . \quad . \quad . \quad (10).$$

These equations are useful when we wish to determine the stress rather than the strain in a body. For instance, if the co-efficients of elasticity, k and n, are increased in the same ratio to any extent, the displacements of the body are proportionally diminished, but the stresses remain the same, and, though their distribution depends essentially on the elasticity of the various parts of the body, the values of the internal forces do not contain the co-efficients of elasticity as factors.

There are two cases in which the functions may be treated as functions of two variables.

The first is when there is no stress, or a constant pressure in the direction of z, as in the case of a stratum originally of uniform thickness, in the direction of z, the thickness being small compared with the other dimensions of the body, and with the rate of variation of strain.

The second is when there is no strain, or a uniform longitudinal strain in the direction of z, as in the case of a prismatic body whose length in the direction of z is very great, the forces on the sides being functions of x and y only.

In both of these cases $S = 0$ and $T = 0$, so that we may write

$$P = \frac{d^2C}{dy^2} - V \qquad U = -\frac{d^2C}{dxdy} \qquad Q = \frac{d^2C}{dx^2} - V \quad . \quad . \quad (11).$$

This method of expressing the stresses in two dimensions was first given by the Astronomer Royal, in the "Philosophical Transactions" for 1863. We shall write F instead of C, and call it AIRY'S Function of Stress in Two Dimensions.

Let us assume two functions, G and H, such that

$$F = \frac{d^2G}{dxdy} \text{ and } V = \frac{d^2H}{dxdy} \quad . \quad . \quad . \quad . \quad . \quad (12),$$

then by THOMSON and TAIT, § 694, if α is the displacement in the direction of x

$$2n\,(\sigma + 1)\,\frac{d\alpha}{dx} = \mathrm{P} - \sigma\,(\mathrm{Q} + \mathrm{R}) \quad . \quad . \quad . \quad . \quad (13).$$

CASE I.—If $\mathrm{R} = 0$ this becomes

$$2n\,(\sigma + 1)\,\frac{d\alpha}{dx} = \frac{d^2}{dxdy}\left\{\frac{d^2\mathrm{G}}{dy^2} - \sigma\,\frac{d^2\mathrm{G}}{dx^2} + (\sigma - 1)\,\mathrm{H}\right\}.$$

Integrating with respect to x we find the following equation for α—

$$2n\,(\sigma + 1)\,\alpha = \frac{d}{dy}\left\{\frac{d^2\mathrm{G}}{dy^2} - \sigma\,\frac{d^2\mathrm{G}}{dx^2} + (\sigma - 1)\,\mathrm{H}\right\} + \mathrm{Y} \quad . \quad (14),$$

where Y is a function of y only. Similarly for the displacement β in the direction of y,

$$2n\,(\sigma + 1)\,\beta = \frac{d}{dx}\left\{\frac{d^2\mathrm{G}}{dx^2} - \sigma\,\frac{d^2\mathrm{G}}{dy^2} + (\sigma - 1)\,\mathrm{H}\right\} + \mathrm{X} \quad . \quad . \quad (15),$$

where X is a function of x only. Now the shearing stress U depends on the shearing strain and the rigidity, or

$$\mathrm{U} = n\left(\frac{d\alpha}{dy} + \frac{d\beta}{dx}\right) \quad . \quad . \quad . \quad . \quad . \quad (16).$$

Multiplying both sides of this equation by $2(\sigma + 1)$ and substituting from (11), (14), and (15),

$$-2(\sigma + 1)\frac{d^4\mathrm{G}}{dx^2dy^2} = \frac{d^4\mathrm{G}}{dy^4} - 2\sigma\,\frac{d^4\mathrm{G}}{dx^2dy^2} + \frac{d^4\mathrm{G}}{dx^4} + (\sigma - 1)\left(\frac{d^2\mathrm{H}}{dx^2} + \frac{d^2\mathrm{H}}{dy^2}\right) + \frac{d\mathrm{X}}{dx} + \frac{d\mathrm{Y}}{dy} \quad (17).$$

Hence

$$\left(\frac{d^2}{dx^2} + \frac{d^2}{dy^2}\right)^2\mathrm{G} + \frac{d\mathrm{X}}{dx} + \frac{d\mathrm{Y}}{dy} = (1 - \sigma)\left(\frac{d^2}{dx^2} + \frac{d^2}{dy^2}\right)\mathrm{H} \quad . \quad . \quad (18),$$

an equation which must be fulfilled by G when the body is originally without strain.

CASE II.—In the second case, in which there is no strain in the direction of z, we have

$$\frac{d\mathrm{Y}}{dz} = \mathrm{R} - \sigma\,(\mathrm{P} + \mathrm{Q}) = 0 \quad . \quad . \quad . \quad . \quad . \quad (19).$$

Substituting for R in (13), and dividing by $\sigma + 1$,

$$2n\,\frac{d\alpha}{dx} = (1 - \sigma)\,\mathrm{P} - \sigma\mathrm{Q}$$

$$= \frac{d^2}{dxdy}\left\{(1 - \sigma)\,\frac{d^2\mathrm{G}}{dy^2} - \sigma\,\frac{d^2\mathrm{G}}{dx^2} + \sigma\mathrm{H}\right\} \quad . \quad . \quad . \quad (20),$$

with a similar equation for β. Proceeding as in the former case, we find

$$\left(\frac{d^2}{dx^2} + \frac{d^2}{dy^2}\right)^2\mathrm{G} + \frac{d\mathrm{X}}{dx} + \frac{d\mathrm{Y}}{dy} = \frac{\sigma}{1 - \sigma}\left(\frac{d^2}{dx^2} + \frac{d^2}{dy^2}\right)\mathrm{H} \quad . \quad . \quad (21).$$

This equation is identical with that of the first case, with the exception of the coefficient of the part due to H, which depends on the density of the body, and the value of σ, the ratio of lateral expansion to longitudinal compression.

Hence, if the external forces are given in the two cases of no stress and no strain in the direction of z, and if the density of the body or the intensity of the force acting on its substance is in the ratio of σ to $(1-\sigma)^2$ in the two cases, the internal forces will be the same in every part, and will be independent of the actual values of the coefficients of elasticity, provided the strains are small. The solutions of the cases treated by Mr AIRY, as given in his paper, do not exactly fulfil the conditions deduced from the theory of elasticity. In fact, the consideration of elastic strain is not explicitly introduced into the investigation. Nevertheless, his results are statically possible, and exceedingly near to the truth in the cases of ordinary beams.

As an illustration of the theory of AIRY'S Function, let us take the case of

$$\mathrm{F} = \frac{1}{2p} r^{2p} \cos 2p\theta \quad . \quad . \quad . \quad . \quad . \quad (22).$$

In this case we have for the co-ordinates of the point in the diagram corresponding to (xy)

$$\xi = \frac{d\mathrm{F}}{dx} = r^{2p-1} \cos (2p-1)\theta \qquad \eta = -r^{2p-1} \sin (2p-1)\theta \quad . \quad . \quad (23),$$

and for the components of stress

$$\left.\begin{aligned} p_{xx} &= \frac{d\eta}{dy} = -(2p-1) r^{2p-2} \cos (2p-2)\theta = -\frac{d\xi}{dx} = -p_{yy} \\ p_{xy} &= \frac{d^2\mathrm{F}}{dx\,dy} = (2p-1) r^{2p-2} \sin (2p-2)\theta \end{aligned}\right\} \quad . \quad (24).$$

If we make

$$\mathrm{G} = \frac{1}{p} r^p \cos p\theta \quad \text{and} \quad \mathrm{H} = \frac{1}{p} r^p \sin p\theta \quad . \quad . \quad . \quad (25),$$

then

$$\left.\begin{aligned} (2p-1) \left(\left|\frac{d\mathrm{G}}{dx}\right|^2 - \left|\frac{d\mathrm{G}}{dy}\right|^2 \right) p_{yy} &= -p_{xx} \\ (2p-1)\, 2 \frac{d\mathrm{G}}{dx} \frac{d\mathrm{G}}{dy} &= p_{xy} \end{aligned}\right\} \quad . \quad (26).$$

Hence the curves for which G and H respectively are constant will be lines of principal stress, and the stress at any point will be inversely as the square of the distance between the consecutive curves G or H.

If we make

$$\left.\begin{aligned} \xi &= \rho \cos \phi \quad \text{and} \quad \eta = \rho \sin \phi \\ \rho &= r^{2p-1} \quad \text{and} \quad \phi = (2p-1)\theta \end{aligned}\right\} \quad . \quad (27).$$

then we must have

If we put

$$q \text{ for } \frac{p}{2p-1} \quad \text{then} \quad \frac{1}{p} + \frac{1}{q} = 2 \quad \text{and} \quad (2p-1)(2q-1) = 1,$$

so that if f, g, h in the diagram of stress correspond to F, G, H in the original figure, we have

$$f = \frac{1}{2q}\rho^{2q}\cos 2q\phi \qquad g = \frac{1}{q}\rho^{q}\cos q\phi \qquad h = \frac{1}{q}\rho^{q}\sin q\phi \quad . \qquad (28).$$

Case of a Uniform Horizontal Beam.

As an example of the application of the condition that the stresses must be such as are consistent with an initial condition of no strain, let us take the case of a uniform rectangular beam of indefinite length placed horizontally with a load $= h$ per unit of length placed on its upper surface, the weight of the beam being k per unit of length. Let us suppose the beam to be supported by vertical forces and couples in a vertical plane applied at the ends; but let us consider only the middle portion of the beam, where the conditions applicable to the ends have no sensible effect. Let the horizontal distance x be reckoned from the vertical plane where there is no shearing force, and let the planes where there is no moment of bending be at distances $\pm a_0$ from the origin. Let y be reckoned from the lower edge of the beam, and let b be the depth of the beam. Then, if $\mathrm{U} = -\frac{d^2\mathrm{F}}{dxdy}$ is the shearing stress, the total vertical shearing force through a vertical section at distance x is

$$\int_0^b \mathrm{U}dy = \left(\frac{d\mathrm{F}}{dx}\right)_{y=0} - \left(\frac{d\mathrm{F}}{dx}\right)_{y=b},$$

and this must be equal and opposite to the weight of the beam and load from 0 to x, which is evidently $(h + k)x$.

Hence

$$\frac{d\mathrm{F}}{dx} = -(h + k)x\phi(y) \quad \text{where} \quad \phi(b) - \phi(0) = 1 \quad . \quad . \quad . \quad (29).$$

From this we find the vertical stress

$$\mathrm{Q} = \frac{d^2\mathrm{F}}{dx^2} + \frac{k}{b}y = -(h + k)\phi(y) + \frac{k}{b}y \ .$$

The vertical stress is therefore a function of y only. It must vanish at the lower side of the beam, where $y = 0$, and it must be $-h$ on the upper side of the beam, where $y = b$. The shearing stress U must vanish at both sides of the beam, or $\phi'(y) = 0$, when $y = 0$, and when $y = b$.

The simplest form of $\phi(y)$ which will satisfy these conditions is

$$\phi(y) = \frac{1}{b^3}(3by^2 - 2y^3) \ .$$

Hence we find the following expression for the function of stress by integrating (29) with respect to x,

$$\mathrm{F} = \frac{h + k}{2b^3}(a^2 - x^2)(3by^2 - 2y^3) + \mathrm{Y} \quad . \quad . \quad . \quad . \quad (30),$$

where a is a constant introduced in integration, and depends on the manner in which the beam is supported. From this we obtain the values of the vertical, horizontal, and shearing stresses,

$$Q = \frac{d^2F}{dx^2} + \frac{k}{b}y = \frac{k}{b}y - \frac{h+k}{b^3}(3by^2 - 2y^3) \quad . \quad . \quad . \quad (31),$$

$$P = \frac{d^2F}{dy^2} = 3\frac{h+k}{b^3}(a^2 - x^2)(b - 2y) + \frac{d^2Y}{dy^2} \quad . \quad . \quad . \quad (32),$$

$$U = -\frac{d^2F}{dxdy} = 6\frac{h+k}{b^3}xy(b - y) \quad . \quad . \quad . \quad . \quad . \quad (33).$$

The values of Q and of U, the vertical and the shearing stresses, as given by these equations, are perfectly definite in terms of h and k, the load and the weight of the beam per unit of length. The value of P, the horizontal stress, however, contains an arbitrary function Y, which we propose to find from the condition that the beam was originally unstrained. We therefore determine α and β, the horizontal and vertical displacement of any point (x, y), by the method indicated by equations (13), (14), (15)

$$2n(\sigma+1)\alpha = \frac{h+k}{b^3}\left\{(3a^2x - x^3)(b-2y) - \sigma x(3by^2 - 2y^3)\right\} - \sigma\frac{k}{b}xy + x\frac{d^2Y}{dy^2} + Y' \quad (34),$$

$$2n(\sigma+1)\beta = -\frac{h+k}{b^3}\left\{\left(by^3 - \frac{1}{2}y^4\right) + 3\sigma(a^2 - x^2)(by - y^2)\right\} + \frac{1}{2}\frac{k}{b}y^2 - \sigma\frac{dY}{dy} + X' \quad (35),$$

where X' is a function of x only, and Y' of y only. Deducing from these displacements the shearing strain, and comparing it with the value of the shearing stress, U, we find the equation

$$\frac{h+k}{b^3}\left\{6a^2x - 2x^3 + 12x(by - y^2)\right\} + \sigma\frac{k}{b}x = x\frac{d^3Y}{dy^3} + \frac{dX'}{dx} + \frac{dY'}{dy} \quad . \quad (36).$$

Hence

$$\frac{d^3Y}{dy^3} = 12\frac{h+k}{b^3}(by - y^2) \quad . \quad . \quad . \quad . \quad . \quad . \quad (37),$$

$$\frac{dX'}{dx} = 2\frac{h+k}{b^3}(3a^2x - 2x^3) + \sigma\frac{k}{bx}, \quad \frac{dY'}{dy} = 0 \quad . \quad . \quad (38).$$

If the total longitudinal stress across any vertical section of the beam is zero, the value of $\frac{dF}{dy}$ must be the same when $y = 0$ and when $y = b$. From this condition we find the value of P by equation (32)

$$P = \frac{h+k}{b^3}\left\{3(a^2 - x^2) + 2y^2 - 2by - b^2\right\}(b - 2y) \quad . \quad . \quad . \quad (39).$$

The moment of bending at any vertical section of the beam is

$$\int_0^b Py\,dy = (h+k)\left(\frac{1}{2}(x^2 - a^2) + \frac{1}{5}b^2\right) \quad . \quad . \quad . \quad . \quad (40).$$

This becomes zero when $x = \pm a_0$ where

$$a_0^2 = a^2 - \frac{2}{5}b^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (41).$$

If we wish to compare this case with that of a beam of finite length supported at both ends and loaded uniformly, we must make the moment of bending zero at the supports, and the length of the beam between the supports must therefore be $2a_0$. Substituting a_0 for a in the value of P, we find

$$P = \frac{h+k}{b^3}\left(3a_0^2 - 3x^2 + 2y^2 - 2by + \frac{1}{5}b^2\right)(b-2y) \quad . \quad . \quad . \quad (42).$$

If we suppose the beam to be cut off just beyond the supports, and supported by an intense pressure over a small area, we introduce conditions into the problem which are not fulfilled by this solution, and the investigation of which requires the use of FOURIER'S series. In order that our result may be true, we must suppose the beam to extend to a considerable distance beyond the supports on either side, and the vertical forces to be applied by means of frames clamped to the ends of the beam, as in Diagram V*a*, so that the stresses arising from the discontinuity at the extremities are insensible in the part of the beam between the supports.

This expression differs from that given by Mr AIRY only in the terms in the longitudinal stress P depending on the function Y, which was introduced in order to fulfil the condition that, when no force is applied, the beam is unstrained. The effect of these terms is a maximum when $y = \cdot 12788\, b$, and is then equal to $(h + k)\cdot 314$, or less than a third of the pressure of the beam and its load on a flat horizontal surface when laid upon it so as to produce a uniform vertical pressure $h + k$.

EXPLANATION OF THE DIAGRAMS (PLATES I. II. III.).

Diagrams I.*a* and I.*b* illustrate the necessity of the condition of the possibility of reciprocal diagrams, that each line must be a side of two, and only two, polygons. Diagram I.*a* is a skeleton of a frame such, that if the force along any one piece be given, the force along any other piece may be determined. But the piece N forms a side of four triangles, NFH, NGI, NJL, and NKM, so that if there could be a reciprocal diagram, the line corresponding to N would have four extremities, which is impossible. In this case we can draw a diagram of forces in which the forces H, I, J, and K are each represented by two parallel lines.

Diagrams II.*a* and II.*b* illustrate the case of a frame consisting of thirty-two pieces, meeting four and four in sixteen points, and forming sixteen quadrilaterals. Diagram II.*a* may be considered as a plane projection of a polyhedron of double continuity, which we may describe as a quadrilateral frame consisting of four quadrilateral rods, of which the ends are bevelled so as to fit exactly. The projection of this frame, considered as a plane frame, has three degrees of stiffness, so that three of the forces may be arbitrarily assumed.

In the reciprocal diagram II.*b* the lines are drawn by the method given at p. 7, so that each line is perpendicular to the corresponding line in the other figure. To make the corresponding lines parallel we have only to turn one of the figures round a right angle.

Diagrams III.*a* and III.*b* illustrate the principle as applied to a bridge designed by Professor F. JENKIN. The loads Q_1 Q_2, &c., are placed on the upper series of joints, and R_1 R_2, &c., on the lower series. The diagram III.*b* gives the stresses due to both sets of loads, the vertical lines of loads being different for the two series.

Diagrams IV.*a* and IV.*b* illustrate the application of AIRY'S Function to the construction of diagrams of continuous stress.

IV.*a* represents a cylinder exposed to pressure in a vertical and horizontal direction, and to tension in directions inclined 45° to these. The lines marked *a*, *b*, *c*, &c., are lines of pressure, and those marked *o*, *p*, *q*, are lines of tension. In this case the lines of pressure and tension are rectangular hyperbolas, the pressure is always equal to the tension, and varies inversely as the square of the distance between consecutive curves, or, what is the same thing, directly as the square of the distance from the centre.

IV.*b* represents the reciprocal diagram corresponding to the upper quadrant of the former one. The stress on any line in the first diagram is represented in magnitude and direction by the corresponding line in the second diagram, the correspondence being ascertained by that of the corresponding systems of lines *a*, *b*, *c*, &c., and *o*, *p*, *q*, &c.

We may also consider IV.*b* as a sector of a cylinder of 270°, exposed to pressure along the lines *a*, *b*, *c*, and to tension along *o*, *p*, *q*, the magnitude of the stress being in this case $r^{-\frac{2}{3}}$. The upper quadrant of IV.*a* is in this case the reciprocal figure. This figure illustrates the tendency of any strained body to be ruptured at a re-entering angle, for it is plain that at the angle the stress becomes indefinitely great.

In diagram IV.*a*—

$$F = \frac{1}{4} r^4 \cos 4\theta \qquad G = \frac{1}{2} r^2 \cos 2\theta \qquad H = \frac{1}{2} r^2 \sin 2\theta .$$

In diagram IV.*b*—

$$f = \frac{3}{4} \rho^{\frac{4}{3}} \cos \frac{4}{3}\phi \qquad g = \frac{3}{2} \rho^{\frac{2}{3}} \cos \frac{2}{3}\phi \qquad h = \frac{3}{2} \rho^{\frac{2}{3}} \sin \frac{2}{3}\phi .$$

Diagrams V.*a* and V.*b* illustrate AIRY'S theory of stress in beams.

V.*a* is the beam supported at C and D by means of bent pieces clamped to the ends of the beam at A and B, at such a distance from C and D, that the part of the beam between C and D is free from the local effects of the pressures of the clamps at A and B. The beam is divided into six strata by

horizontal dotted lines, marked 1, 2, 3, 4, 5, 6, and into sixteen vertical slices by vertical lines marked *a*, *b*, *c*, &c.

The corresponding lines in the diagram V.*b* are marked with corresponding figures and letters. The stress across any line joining any two points in V.*a* is represented in magnitude by the line in V.*b*, joining corresponding points, and is perpendicular to it in direction.

These illustrations of the application of the graphic method to cases of continuous stress, are intended rather to show the mathematical meaning of the method, than as practical aids to the engineer. In calculating the stresses in frames, the graphic method is really useful, and is less liable to accidental errors than the method of trigonometrical calculation. In cases of continuous stress, however, the symbolical method of calculation is still the best, although, as I have endeavoured to show in this paper, analytical methods may be explained, illustrated, and extended by considerations derived from the graphic method.

II.—*On Scientific Method in the Interpretation of Popular Myths, with special reference to Greek Mythology.* By Professor BLACKIE.

(Read 17th January 1870.)

Of all the branches of interesting and curious learning, there is none which has been so systematically neglected in this country as mythology—a subject closely connected both with theology and philosophy, and on which those grand intellectual pioneers and architects, the Germans, have expended such a vast amount of profitable and unprofitable labour. The consequence of this neglect has been, that of the few British books we have on the subject, the most noticeable are not free from the dear seduction of favourite ideas, which possess the minds of the writers as by a juggling witchcraft, and prevent them from looking on a rich and various subject with that many-sided sympathy and catholic receptiveness which it requires. In fact, some of our most recent writers on this subject have not advanced a single step, in respect of scientific method, beyond JACOB BRYANT, unquestionably the most learned and original speculator on mythology of the last century; but whose great work, nevertheless, can only be compared to a grand chase in the dark, with a few bright flashes of discovery, and happy gleams of suggestion by the way. For these reasons, and to make a necessary protest against some ingenious aberrations of MAX MÜLLER, GLADSTONE, INMAN, and COX in the method of mythological interpretation, I have undertaken to read the present paper; which, if it possess only the negative virtue of warning people to be sober-minded and cautious when entering on a path of so slippery inquiry, cannot be deemed impertinent at the present moment.

For the sake of distinctness and compactness, I will state what I have to say in a series of articulate propositions.

I. By the mythology of a people, I understand the general body of their traditions, handing down from the earliest times the favourite national ideas and memories, in a narrative form, calculated to delight the imagination and stimulate the affections of love and reverence.

II. The dress of all mythology, as appealing to the imagination, is necessarily poetical; the contents of it are generally four fold—(1.) Theological; (2.) Physical; (3.) Historical; and (4.) Philosophical and Moral.

III. In the theological and moral myth, the idea is the principal thing, the narrative only the medium; in the historical and physical myth, the fact is the principal thing; what goes beyond the fact is mere scenic decoration or imaginative exaggeration.*

IV. A myth intended to convey an idea is distinguished from an allegory or parable by the consciousness of purpose with which allegories and parables strictly so called are put forth and received.

V. As it has been well said of popular proverbs, that they are the wisdom of many and the wit of one, so theological and moral myths grew up in the popular imagination, and were nursed there till in happy season they received a definite shape from some one representative man, whose inspiration led him to express in a striking form what all felt to be true and all were willing to believe.

VI. The first framers of myths were, no doubt, perfectly aware of the real significance of these myths; but they were aware as poets, not as analysts. It is not, therefore, necessary to suppose that in framing these legends they proceeded with the full consciousness which belongs to the framers of fables, allegories, and parables. A myth is always a gradual, half-conscious, half-unconscious growth; a parable is the conscious creation of the moment.

VII. During a certain early stage of national life, which cannot be accurately defined, but which always precedes the creation of a regular written literature, the popular myth—like a tree or a plant—becomes subject to a process of growth and expansion, in the course of which it not only receives a rich embellishment, but may be so transformed by the vivid action of a fertile imagination, and by the ingrafting of new elements, that its original intention may be altogether obscured and forgotten. How far this first significance may in after times be rightly apprehended, depends partly on the degree of its original obviousness partly on the amount of kindred culture possessed by the persons to whom it is addressed.

VIII. As of essentially popular origin and growth the myth cannot, in the proper sense, be said to have been the creation of any poet, however distinguished. Much less could a popular minstrel, like HOMER, using a highly polished language, and who manifestly had many predecessors, be said to have

* Sometimes, however, a historical person, like FAUST, may be seized on by the people, merely as a convenient vehicle for embodying a floating mass of mythological notions. In this case the person is really a secondary consideration: a real person he remains, no doubt; but, for a legendary nucleus, any other person would have done as well.

either created the characters or invented the legends about the Greek gods, which form what the critics of the last century used to call the machinery of his poems. In regard to theological myths, which are most deeply rooted in the popular faith, such a poet as HOMER could only turn to the best account the materials already existing, with here and there a little embellishment or expansion, where there was no danger of contradicting any article of the received imaginative creed.

IX. The two most powerful forces which act on the popular mind, when engaged in the process of forming myths, are the physical forces of external nature, and the more hidden, though fundamentally more awful powers of the human will, intellect, and passions. It is to be presumed, therefore, that all popular myths will contain imaginative representations of both these powers; and, in their original shape, they are in fact nothing more than the assertion of the existence of these two great classes of forces in a form which speaks to the imagination—that is, in the form of personality; and there will be a natural presumption against the adopting of any system of mythological interpretation which ignores entirely either the one or the other of these elements. If this proposition be correct, the objections of MAX MÜLLER (Chips, ii. 156) to the Greek derivation of Ἐρινύς, from the old Arcadian ἐριννύειν (PAUSAN. viii. 25, 6), are unfounded.

X. The most fertile soil for purely theological myths is polytheism; and the most obvious as well as the largest field for a religion of multiform personalities, is external nature. In the interpretation of such myths, therefore, we shall be justified in searching primarily for the great forces and phenomena of the physical world, as underlying the imaginative narrative and imparting to it its true significance; and in proportion to the prominence of these phenomena, and the potency of these forces, will the probability be that we shall find them fully represented in any body of polytheistic theology.

XI. As the essence of polytheism thus consists in the habitual elevation of what we call physical facts and forces into divine personalities, the line betwixt a purely physical myth and a theological myth will naturally be extremely difficult to draw. Zeus, for instance, as the Thunderer, represents a physical fact as well as a theological doctrine; nevertheless, it would be wrong to assume that there is no such element in tradition as a strictly physical myth. Certain striking facts of volcanic action or geological change, strange and grotesque shapes of rocks and other natural objects, unusual conformations of landscape, not to mention the occasional discovery of gigantic fossil bones, and even entire skeletons of animals no longer existing, might well

form the basis of what is properly termed a physical or a geological, rather than a theological myth; and, as HARTUNG well remarks (Gr. Myth. i. p. 168), notable recurrent events in nature, such as the heavy rains at the end of summer, are peculiarly calculated to impress the popular imagination, and to produce myths.

XII. But as to man there is, after all, nothing more interesting and more important than man, it is in the highest degree unreasonable, in the interpretation of myths, to proceed on the assumption that all myth is idea, and that no myth contains any historical element. It may be true, no doubt, that in the case of some particular nation, all action of the popular imagination on human personalities has been excluded; but such a one-sided action is not to be presumed; it must be proved; and that in such a rich and various mythology as the Greek all reference to human characters and human exploits should be systematically excluded is in the highest degree improbable. In a country where the gods descended so easily into humanity, it were strange if men had not occasionally ascended into godhood.

XIII. In a theology so thoroughly anthropomorphic as the Greek, the distinction between the divine and human element will sometimes be difficult to trace; for the same feelings, situations, and actions will necessarily belong to human gods and to godlike men. But this state of the case, in the interpretation of any particular myth, is a ground for doubt, not for dogmatism. It includes the possibility or the probability of one or two explanations, but the certainty of neither.

XIV. The incredible exaggerations or embellishments with which the name of any national hero may have been handed down in a popular myth afford no presumption against the genuine historical character of its nucleus. On the contrary, it is just because extraordinary characters have existed, that extraordinary and incredible, miraculous and even impossible stories are invented about them. A plain, sober, critical, matter-of-fact account of its early popular heroes is not to be expected from any people.

XV. The error of certain ancient rationalising interpreters of the Greek myths did not consist in presuming historical fact as the nucleus of some myths, but in the indiscriminate application of the historical interpretation to all myths, and that often in a very prosaic and altogether tasteless way.

XVI. The error of certain modern idealising interpreters of the Greek mythology does not consist in endeavouring to recover the ideas which

originally lay at the root of some myths, the full significance of which had been lost so early as HOMER, but in the partial and one-sided application of a few favourite ideas to all physical facts, and in the broad denial of any historical elements underlying any personality of early tradition.

XVII. Among the ancients, the extreme of the rationalising interpretation of the Greek theological myths is what may be called the irreligious, godless, and altogether prosaic system of EUHEMERUS (B.C. 300), who wrote a book to prove that all the Greek gods, not even excepting Jove, had been originally dead men deified. The error of this system consisted, not in the assertion that the elevation of extraordinary human characters to a divine rank with religious honour after death, is an element traceable in the Hellenic, as in some other popular theologies, but in the wholesale declaration that religious worship had no other origin, and that this element, which is always secondary and derivative in the popular creed, is primitive and exclusive.

XVIII. In order to ascertain how far the principle of EUHEMERUS may apply to any particular case, the general religious tendencies and habits of the nation or people must be considered in the first place, and then the whole circumstances and features of the mythical narrative must be accurately surveyed and carefully weighed, and a separation of the canonised man from the deified nature element with which he may have been mixed up, made accordingly.

XIX. EUHEMERUS, however, was altogether wrong in supposing that this system of interpretation could be applied on any extensive scale to the mythical theology of the Greeks; and the few French and English writers who, in the flatness of the last century, gave a limited currency to this idea, have found no followers in the present.

XX. An opposite theory to that of EUHEMERUS, much in fashion with the Germans, is that, whereas he said the gods were elevated men, we ought rather to say that many men, perhaps all the heroes of legendary story, are degraded gods. That in the course of religious development, especially when mixed up with great changes in the political relations of different races, such a degradation may have taken place is certain; that it has taken place in certain special cases will be a just conclusion from an analysis of the character and worship of certain heroes, when a cumulative view of the myths connected with them suggests the theory of a divine rather than a human significance; but there is no scientific warrant for the assertion which it is now the fashion to make (BARING GOULD, Rel. bel. vol. i. p. 167), that the old heroic names of a country, as King ARTHUR, for instance, are in the mass to be treated as degraded gods.

XXI. The best authorities for the facts of a myth are not always the poets, nor even the most ancient poets, as HOMER, who in the exercise of their art often took large liberties with sacred tradition; but the reliable witnesses are rather such as PAUSANIAS, who record the old temple lore in its fixed local forms. This distinction, often forgotten, has given rise to not a little confusion, and created some needless difficulty in mythological interpretation; and HARTUNG (i. 184) has done important service to comparative mythology by drawing attention emphatically to the difference between sacred LEGENDS as believed by the people, and religious MYTHS freely handled by the poets.

XXII. In the interpretation of any popular myth, the first thing to be done is to ascertain carefully what the thing to be interpreted actually is; and this can only be done by collecting all the facts relating to it, working them up into a complete, and if possible consistent picture, and not till then attempting an explanation. Now, as the facts relating to any single god, let us say in the Greek Pantheon, are scattered over a wide space, and come from various sources, to attempt the explanation of these facts without the previous labour of critical and well-digested scholarship, may be an ingenious amusement, but never can be a scientific procedure. All the facts must be collected, and all the criticisms weighed, before a verdict can be pronounced.

XXIII. But the mere collection of facts will never help a prosaic or an irreverent man to the interpretation of what is essentially poetic and devout. A book supplies what must be read; but the eye that reads it can see only what by natural faculty and training it is fitted to see. As the loving and reverential contemplation of nature was the original source of the polytheistic myths, so the key to them will often be recovered by a kindred mind acting under influences similar to those which impressed the original framers of the myth; and if this may be done with a considerable amount of success by a poetical mind, acted on by nature in any country, much more will such success be achieved by such a mind in the country where the myths were originally formed. But as the aspects of nature are various, and the fancies of poetic minds no less so, it will always be necessary to verify any modern notion of an ancient deity, thus acquired, by confronting it accurately and continuously with the traditional materials contained in books and works of art. Highly poetical minds, such as SHELLEY, KEATS, and RUSKIN, when dealing with Greek mythology, without the constant correction of accurate scholarship, are not seldom found using Greek myths to represent modern ideas, rather than human ideas to interpret Greek myths. And the example of the Germans proves, that in minds naturally fertile and ingenious, no amount of erudition affords a safeguard against the besetting sin of mythological interpreters, to find in all myths a select field and enclosed

hunting ground for the pleasant disport of an unfettered imagination. Discoveries are easy to make in a region where plausibility so readily gains currency for proof.

XXIV. An important aid in the interpretation of myths will often be supplied by the etymology of the names of the mythological personages; and in this way new deities will sometimes be found to have arisen from the mere epithets of old ones, as JACOB BRYANT saw clearly nearly 100 years ago; nay, even magnificent myths may at times be traced to no more sublime origin than a false etymology which had taken possession of the popular ear. The significance of divine names must, of course, be sought in the first place in the language to which the mythology belongs; but in applying this test, with the view of obtaining any scientific result, great care must be taken to avoid treating doubtful etymologies in the same way that certain ones may be treated. For where the etymology is uncertain, that is, does not shine out plainly from the face of the word (as in the case of the Harpies in HESIOD), then the elements of doubt are often so many, that it is wiser to abstain altogether from this aid, than to attempt founding any serious conclusions upon it. For, in the first place, we may not have the word in its original form; and, in the second place, two or three etymologies may be equally probable. The best etymologies, whatever BRYANT, and INMAN, and MAX MÜLLER may say to the contrary, are only accessories of scientific mythological interpretation.

XXV. If the mythological names have no significance in the language to which they belong, then reference may be made to cognate languages; and in the case of European tongues, with propriety to the Eastern sources from which they are demonstrably derived. But here a double caution is necessary; for accidental resemblances may be found in all languages, and extensive learning, coupled with a vivid imagination, may readily supply the most plausible foreign derivations, which are merely fanciful.

XXVI. By referring to another, and it may be a more primitive and ancient language, for the etymological key to a religious myth of any people, we are treading on historical ground extrinsic to the people with whose myths we may be dealing. For comparative philology, like archæology, recovers the earliest history of a people before writing was known; and this raises the inquiry, whether a mythology which bears a foreign nomenclature on its face may not convey foreign ideas in its soul—that is, to take an example, whether the Greek mythology, if the names of its personages are more readily explained in Hebrew or Sanscrit than in Greek, may not in respect of its ideas and legends be more properly interpreted from original Hebrew or Sanscrit, than from native

Greek sources? And may we not hope, in this way, in the Hebrew Scriptures, or the Sanscrit Vedas perhaps, to put our fingers on the ancient germs of those anthropomorphic myths which HOMER and HESIOD present to us in adult completeness and full panoply? and thus the highest end of scientific research will be obtained, not only to dissect the flower, but to trace it to the seed, and follow it through every stage of its rich and beautiful metamorphosis.

XXVII. The prospect this holds out of tracing famous European religious myths to their far home in the East is extremely inviting.* It satisfies at once scientific minds by the promise of going to the root of a matter which has hitherto been treated superficially, and that not inconsiderable class of literary men and scholars who have a keener eye for an ingenious novelty, than for a stable truth. When we bear in mind also the significance of the homely proverb, that "far birds have fair feathers," and the well-known fact, that every mother is apt to prefer her own bairn to others which may be more healthy and beautiful, we shall see reason to proceed, not without hope indeed, but with more than Scottish caution, in this Oriental adventure. There is a class of persons in the world who have a strange pleasure in travelling a thousand leagues to quarry out a truth, which they might have picked up from beneath their nose. Against these seductions therefore, in the first place, while prosecuting this foreign chase, we must be on our guard. We ought to know that we are hunting on very deceitful ground; that we are dealing with a class of phenomena, that, like clouds and kaleidoscopic figures, are very apt to change their shape, not only by their own nature, but specially also according to the position of the observer; and that the same nebulous conglomerate may at one moment look very like a whale, at another moment very like Lord BROUGHAM, and at a third moment very like Olympian Jupiter. And in the prospect of such a possible ridiculous conclusion to the sublime adventure on which he is starting, every inquirer into the remote origin of European myths ought to take with him these cautions—

(1.) That there is no necessity and no scientific warrant for seeking a foreign explanation of deities, which already sufficiently explain themselves by the character which they bear, or the symbols which they exhibit in their own country.

(2.) That the formative power by which myths were created, viz., the imagination, possesses a wonderful magic, in virtue of which the materials on which it acts, especially with a quick and vivid people unfettered by formal creeds, are subjected to a perpetual process of transmutation, which renders the recognition of the original identity of two diverging myths an extremely difficult and

* "The whole theology of Greece was derived from the East."—BRYANT, vol. i. p. 184.

not seldom an altogether hopeless task. In this respect the recognition of the original identity of different words in cognate languages by comparative philology is a much more safe and scientific process than a similar recognition of the identity of different persons of two Pantheons through the shifting masks of comparative mythology.

(3.) That the principal relations under which the great objects of nature, such as the sky, the sun, the sea, &c., may appear, when subjected to the process of imaginative impersonation, are in many cases so obvious that two different polytheistic peoples may easily hit upon them without any historical connection. Even in the free exercise of poetical talent in the case of individual poets of highly potentiated imagination, we constantly stumble on comparisons which have been made independently by other poets at other times or in distant countries, and which superficial critics are sometimes eager to fasten on as plagiarisms; much more, in the vulgar exercise of the imagination, by the mass of the people on certain given natural objects may we expect frequent instances of coincidence without connection. This consideration will restrain a prudent investigator in this department from building any theory of foreign origin of myths on a few points of natural similarity.

Taking these cautions along with us, we now observe, in reference to the probable Eastern origin of certain Greek myths—

XXVIII. That the borrowing of one nation from another in the province of mythological ideas, as in the case of philological materials, may take place in a twofold fashion, either in the way of original descent from a common stock, far back in the cradle of the race, or by importation through the medium of commerce or great religious revolutions and invasions. Of these two methods of borrowing, it is impossible to say, *a priori*, which promises the greater amount of gain to the adventurous inquirer; for, while the advantage of greater closeness belonging to the original identity of stock may be in a great measure neutralised by the distance of time and place, and the changes which they induce, the disadvantage of a more loose connection which belongs to the foreign importer may be amply compensated by the firm hold which the commerce, and polity, and intelligence of a superior people may take of an inferior people.

XXIX. It must be borne in mind, also, that the recognition of a supposed identity between the gods of any two polytheistic peoples may easily take place without any real borrowing. For the desire of harmonising and classifying discordant phenomena, which belongs to the very nature of intellectual action, is particularly displayed in the field of popular religion—to such an extent, indeed, that it became a fixed habit of the Greek and Roman mind to identify the deities of foreign countries with their own native deities by certain signs more

or less superficial. The testimony of the Greeks, therefore, with regard to the supposed identity of certain personages in their Pantheon with certain gods or goddesses in the Egyptian or Phœnician, and their consequent foreign extraction, will require to be examined with the severest scrutiny.

XXX. In deriving any god from a foreign source, even though his foreign origin should appear in some respects perfectly certain, we must not conclude that all the phenomena which his person and character present are to be explained from abroad. Nothing is more natural than that he should be a compound god, one half native and one half foreign, or even a monstrous conglomerate of many gods.

XXXI. Of all the foreign sources to which the Hellenic mythology has at different times been referred by the learned, Egypt is at once the most reputable and the least likely. For here we have neither original connection by identity of stock, nor any such commercial or political action of the more ancient over the more modern people, as would lead to the importation of religious ideas. The ancient Greeks had a great respect, and a sort of awful reverence for the wisdom and the antiquity of the Egyptians; but this respect and reverence was more likely to lead them, as in fact it often did, to the recognition of superficial resemblances (as in the case of Io and Isis), than to the trace of original identity. Modern researches have added nothing to the probability of the favourite notion of Bryant and Blackwell, that the principal persons and legends of Hellenic mythology came directly from the land of Ham.

XXXII. For the Hebrew origin of some of the Greek theological ideas—the darling notion of Church Fathers and Protestant theologians, and which has been recently revived by a statesman of distinguished character, talent, and erudition—there is even less to be said. For, in the first place, here we are comparing a polytheistic system with a monotheistic, where antagonism rather than similarity is to be looked for; the elements of original or superinduced connection between the two peoples are altogether wanting; and the original unity of the human family, which is the only link that binds the Greek to the Jew, is so remote that it requires no inconsiderable amount of hardihood to drag them into the arena of the present comparison. This hardihood, however, has never been wanting; and besides its own virtue, has always found great favour with the religious public, which is pleased with nothing so much as the idea that everything good, beautiful, or excellent in any way that heathen religions may be allowed to possess must have come either from the Hebrew Scriptures directly, or from some more ancient source of primeval revelation. And no doubt there may be a certain truth in this view; but it is

a truth which affects the monotheistic element, that in the person of Zeus lies the background of the Hellenic polytheism, rather than the polytheistic personages to whom it has been applied. A consciousness of this, no doubt, led the early mythological interpreters of this school to apply the principle of EUHEMERUS largely to the Old Testament, in such a way only as to recognise the venerable Hebrew patriarchs under various masks of old Pelasgic gods or demigods.

XXXIII. For the Phœnician influence on the formation of the early Greek theology there is much more to be said. We can, indeed, scarcely imagine a race of such distinguished merchants and navigators, commanding the Greek seas in the early ages of European civilisation, without supposing some such contagion and ingrafting of religious ideas, as the genius of polytheism was on all occasions prone to invite. We shall, therefore, be disposed to receive favourably any distinct proof, or even probable indication, of the derivation of Greek gods from a Phœnician source; but we must bear in mind at the same time, that the Phœnicians were known to the Greeks as mere traders, with temporary settlements on the coast of the Mediterranean, and that their character, as exhibited in the Odyssey, was by no means possessed of such attractions as might aid to allure the Greeks to the adoption of any of their peculiar objects of worship.

XXXIV. The last source of Greek myths, for which a strong claim has recently been put forth by a German of distinguished talent, taste, and learning in this country, is Sanscrit. And here at last some people seem to think, that with all certainty we have got at the true source of the many-winding mythological Nile. But after looking into this matter with all possible care, and with no prejudice whatever (for nothing would please me so much as to catch the infant Mercury in the bosom of a cloud, floating over the shining peak of the Hindoo Koosh, or to hook Proteus in one of his many forms at the mouth of the Ganges), I must honestly confess, that hitherto the interpreters of Hellenic myths from Sanscrit roots and Vedic similes have inspired me rather with distrust than with confidence. The principal characters of the Hellenic Pantheon tell their own story, to a poetical eye, more obviously and effectively than with the help of a Sanscrit root; and those few of them which are more doubtful, such as Hermes and Athena, seem to be precisely those in which the Sanscritizing mythologers have most egregiously failed. I consider, therefore, that, while the Vedic mythology, preferably to any other polytheistic system, presents an ample field from which some of the Hellenic legends may be aptly illustrated, and a few, perhaps, correctly interpreted, the attempt to explain the great and prominent phenomena of the Greek Pantheon, by an ingenious application of a few favourite physical ideas variously impersonated

by the fancy of the Vedic poets, must be regarded in the meantime, at least, as a failure.*

XXXV. Without, therefore, in the slightest degree wishing to throw discouragement on the delightful and interesting study of comparative mythology,—a study that promises the most fruitful results in the domain of theology and moral philosophy,—the procedure of exact science seems to demand that, before venturing on extensive excursions into foreign regions, we should, in the first place, carefully survey and exhaust our home domain—that is to say, that the Greek traditions with respect to their gods, interpreted by themselves, and the general principles of mythical interpretation laid down in the above propositions, afford a surer basis for this branch of mythological science than hints suggested by Oriental etymologies, or analogies from the Vedic hymns. And in order to make this more clear, I will select a few examples of person ages from the motley theatre of Hellenic legend, which may be best adapted for testing the value of the different methods of interpretation.

XXXVI. As examples of how the elemental significance of the Hellenic gods reveals itself to a sympathetic eye, from the mere presentation, epithets, attitudes, and badges of the mythologic personages, we need do no more than mention *Zeus*, *Poseidon*, and *Apollo*, in whom all the ancients, who exercised reflection at all on the matter, recognised, with one voice and by an unerring instinct, the great elemental powers of the sky, the sea, and the sun. And these are precisely the powers which, from their prominence, might *a priori* have been predicated as certain to obtain a conspicuous place in an anthropomorphic Pantheon of elemental origin. Of these three great gods also, be it noted, that the first is the only one of which we can trace the etymology with any certainty; but neither does this one etymology, when recognised in the Sanscrit word *Diva*, to *shine*, add anything to the already recognised idea of the Hellenic Zeus, nor does the lack of an etymon in the other two cases render our perception of the character of the two gods less clear, or our knowledge of their significance more certain. With regard to Poseidon, Mr Gladstone's recent attempt to fix on him a Phœnician pedigree must be regarded as unsuccessful. The people who at an early period sailed to Colchis and to Troy, did not require to borrow a lord of the flood from the merchants of Tyre and Sidon.

XXXVII. In *Hera* who, to the people and the people's poet, was simply the spouse of Zeus, a large class of ancient speculators, as is well known, were

* It may be proper to state, that the interpretation of certain personages in the Greek Pantheon from sources of Sanscrit etymology, to which Max Müller has given currency, is not at all confirmed by the judicious sobriety of our countryman Dr Muir. See his paper in our Transactions, vol. xxiii. p. 578.

inclined to recognise the lower region of the atmosphere, of which Zeus represented the *αἰθήρ*, or upper region. But a little consideration has convinced most modern interpreters that this idea was a mistake. When by the completion of the anthropomorphic process, the original *οὐρανός* had become "Father Jove," it was most natural that his elemental counterpart *Γῆ*, Mother Earth, should become the matron Hera; and with this supposition, the well-known description of the sacred marriage of Zeus and Hera (Il. xiv. 345), together with the cow-symbolism belonging to the *Βοῶπις*, and her Argive priestess Io, notably harmonise. It is no objection to this view, that Ceres or Demeter is also the anthropomorphised earth; for "the many names of one shape" (*πολλῶν ὀνομάτων μορφὴ μία*), characteristic of the oldest elemental theology, could easily, and did often crystallise into two or more shapes of one power. We shall, therefore, say with no rash confidence, that the Hellenic Hera means the earth; and we readily allow the etymological conjectures connected with her name to remain conjectures.

XXXVIII. On *Athena*, MAX MÜLLER says, "The Sanscrit root AH, which in Greek would regularly appear as ACH, might likewise then have assumed the form of ATH; and the termination ENE, is Sanscrit ANA" ("Science of Language," vol. ii. p. 503); and again, "How Athena being the *Dawn*, should have become the goddess of wisdom, we can best learn from the Vedas. In Sanscrit, *Budh* means to *wake* and to *know*" (Do. p. 504).

But this is manifestly following out a favourite idea upon theories of the most flimsy texture. If any etymology is to be sought for the syllable AΘ, the native root *αἰθ* which signifies to glow, corresponding as it does with the familiar epithet of *γλαυκῶπις*, or "flashing-eyed" (which I think WELCKER suggests), is preferable to that suggested by the distinguished Sanscrit scholar. But here, as in other slippery cases, the principles laid down in the preceding propositions lead me to set etymology aside, and to look at the finished figure of the goddess, with her badges, relations, and actions, as the natural and sure index to her significance. Now if Zeus, according to the Greek conception, was the strong, stormy, and thunderous element of the sky—as his epithets *κελαινεφής*, and *ἐριβρεμέτης*, and *τερπικέραυνος*, sufficiently declare—his flashing-eyed daughter, who alone is privileged to wield his thunderbolt (ÆSCHYL. Eumen., 814), must be some action or function of the sky. Let her, therefore, be the flashing lightning, or the bright rifted azure sky between the dark rolling thunder clouds, or both if you please, and you have at once an elemental theory which explains adequately her anthropomorphic parentage and presentation. As to her moral and mental significance, that follows necessarily from her Jovian fatherhood. When the all-powerful was recognised as at the same time the all-wise, and the great counsellor (*μητίετα Ζεύς*), his daughter, as a matter of course, became the

goddess of practical wisdom, that is, of the great arts of peace and labour (as the vases largely show), and the patron and protector of all men of valour like Achilles, and of sagacity like Ulysses.

XXXIX. The Hellenic *Hermes* is one of those mythological personages who from an originally simple root, has grown up into such a rich display of graceful ramification, that, when we approach him from his most familiar side we are the least likely to interpret his true significance. But if we attend to the earliest indication of his functions as found in Homer, and as displayed in the familiar phallic symbol (Herod. ii. 51), we can have no difficulty in evolving, by a series of graduated expansions, his final avatar as a god of eloquence, from his original germ as a pastoral god of generation and increase (Hom. Il. xiv. 491). As the god of shepherds and mountaineers, he was necessarily the guide of all wanderers through the many winding glens, and across the many-folded hills of the Arcadian Highlands. This early function accordingly appears in Homer: he is the friendly guide of all persons who have lost their way or who wander in the dark (Od. x. 277; Il. xxiv. 334). His connection with music and with wrestling, the natural recreations of a pastoral people, of course belong to this his earliest Hellenic character. Afterwards, when in the necessary progress of society, the patriarchal shepherd of the hills resigned his social position into the hands of the rich merchant of the great towns, Hermes became the god of gain generally; and, with gain, of all those arts of adroitness and sharpness which belong to the career of a successful trader. The kindly guide of night-wandering shepherds has now become the expert negotiator, and the trusty messenger; he is the winged servant of the gods above; and among men his oaten pipe is exchanged for the charm of winged words, which sway the counsels of the wise, and soothe the clamours of the turbulent. With this natural and obvious interpretation of a purely Hellenic deity, as given within the bounds of Greece itself, we shall raise only a brilliant confusion, if we follow Max Muller across the Hindoo Coosh, and ingeniously attempt to find the germ of the Pelasgic shepherd god in the breeze of the early dawn, which ushers in the march of the busy day. Such remote conjectures may be both beautiful and ingenious, but they are a mere play of fancy, and travel obviously far out of the way of a sober, a scientific, and a stable interpretation.

XL. *Dionysus* was a god of comparatively recent introduction into Greece (Herod. ii. 49), confessedly of Asiatic origin, and in whom the union of fervid wine with the phallic symbol and violent orgies, can leave no doubt as to his true character. He is the male god of generation, according to the Asiatic conception, as the Syrian goddess of Lucian (De Dea Syria, 16) was

the female one; and the old Heraclitan principle that fire is the origin of all things, rudely conceived by the popular imagination, is manifestly that which in this god identifies the fervour of the vine juice, the brewst of the sun, with the fervour of the generative process. The fact that the worship of Dionysus was not native in Greece, but travelled from the East, naturally led to the representation of this god as a wonderful conqueror, in the fashion of SESOSTRIS and ALEXANDER the Great; from which analogy, coupled with his preaching the gospel of wine, BRYANT and other speculators have been eager to find in him a perverted NOAH; but the application of the principle of EUHEMERUS in this case evidently rests on too slender a foundation to afford any grounds for a scientific interpretation.

XLI. *Aphrodite* is that goddess in whose case Mr GLADSTONE'S favourite idea of Phœnician influence on the Greek Pantheon has long been recognised as the most certain (HEROD. i. 105; PAUSAN. i. 14, 6). The recognition of this Phœnician element, however, does by no means imply that the existence of an original Hellenic impersonation of the passion of love, and the seductions of personal beauty, should be denied. On the contrary, the female deity whom the Phœnicians were seen worshipping in their factories on the coasts of the Mediterranean, would most probably be accepted by the ancient Pelasgic tribes chiefly because they found in her attributes a striking identity with their own native Aphrodite.

XLII. Phœnician influence is also undoubtedly to be acknowledged in the very complex and composite mythology connected with the name of *Heracles.* But the person of Heracles, as we find him in HOMER, exhibits nothing beyond the exaggerated traits of a stout and muscular humanity in combat with fate and circumstance, and the wild beasts of the forest—a plain Hellenic counterpart, in fact, to the Hebrew SAMSON, of whose historical reality, to a mind not violently possessed by German theories, there cannot be the slightest reason to doubt. The exaggerations connected with his story are the natural and necessary effects of the excited popular imagination brought to bear on such a character; but these exaggerations, taken at their highest, are exhibited on a very small platform in HOMER, and present a very modest array of achievements compared with the multiform mass of myth that afterwards accumulated round this representative Greek hero. The principle of growth, of such luxuriant vitality in popular myths, has been obviously at work here; and the sort of omnipresence latterly attributed to this wandering queller of monsters is most readily explained from the influence of the Phœnician factories in the Mediterranean, in whose Melcarth the Greeks delighted to recognise their own stout son of Jove and Semele. And if this Tyrian Hercules, as Phœnician

scholars incline to believe (MOEVERS, vol. i. p. 385), really was a sun god, the twelve labours of Hercules will, of course, only be the symbolical expression for the progress of the Titan sun through the twelve months of the solar year. This the ancients themselves, in the Orphic theology, at least distinctly recognised.

XLIV. In *Bellerophon* the Germans find a favourite example of their theory, that all the heroes of the so-called heroic age are the degraded gods of an early elemental worship. How this theory is worked out in the present case it may be instructive to consider. The winged steed, of course, brings you at once into the region of the sun. Then you turn up EUSTATHIUS' commentary on the well-known episode of the Corinthian hero in the sixth book of the Iliad (v. 181), and you find there that there was an old Greek word ἔλλερος, used by CALLIMACHUS, which is equivalent to κακός or *bad;* but bad things are black things; therefore, with the help of the digamma, transmuting ἔλλερος into βελλερος, we arrive at the conclusion that βελλεροφόντης means the slayer of darkness, and, of course, can be nothing but the light, or the sun. Bellerophon is thus, by a dexterous etymological feat, already a solar god in full panoply; and when, in addition to this, we find that the worship of the sun was much practised at Corinth, the native place of the hero, and that he died in Lycia, a country famous for its devotion to the same deity, the case for a degraded Ἥλιος seems to be satisfactorily made out. But, on the other hand, the oldest version of the story in HOMER has no hint of the winged horse; and for the rest, looks in every trait as much like a purely human history of those early Greek times as the story of ST COLUMBA shows like a real legend of a real Catholic apostle in early Christian times. We shall, therefore, in my opinion, more wisely say that the airy flight of the grandson of Corinthian Sisyphus on his winged Pegasus, is only the imaginative painting out of a real human journey made from such real and natural causes as those which HOMER details; and, if the winged horse has anything to do with the worship of the sun at Corinth, it is more reasonable to suppose that such a blazon should have been added for the glorification of a real great man, than that all the great men of early Corinth should have been clean swept from the popular memory to make way for an unmeaning Pantheon of degraded and forgotten gods.

XLV. Descending lower down into the region of what has the aspect, not of metamorphic theology, but of plain human fact, we may take the names of *Achilles* and *Theseus* as examples of how far the German school is inclined to carry its peculiar tactics of finding nothing in all early tradition but theological ideas and symbols. As to Achilles, the favourite notion with most German writers is that this hero is a water god,—a notion founded on nothing that I can see, save on the etymological analogy of Achelous, the happy coincidence of

Peleus with the Greek name for mud (πηλός), and the fact that the mother of the hero was a sea-goddess; and on this notion FORCHHAMMER, I believe, or some one of the erudite fancymongers beyond the Rhine, constructed a theory that the Iliad is really a great geological poem, in which water power is represented by Achilles, and land power by Hector (from ἔχω, to hold, restrain, keep back)! This is really too bad. If a man in Thurso, to take a modern example, named WATERS—and it is a characteristic name in that quarter, were to marry a woman called LOCH—a well-known name in Sutherland—and a daughter, the offspring of this marriage, should join herself in wedlock to an English gentleman named RIVERS, no sane person could see in this conjunction of congruous etymologies anything but one of those curious coincidences which amuse a newspaper reader for a minute, and then are forgotten. Why, then, we ask, should the occurrence of *water*, and *mud*, and a *sea-nymph*, among the family names of an old Thessalian throne, be supposed to possess any more profound significance, even on the supposition that the etymologies are certain, which they certainly are not? And accordingly, we find this favourite water theory discarded by the Germans themselves, the moment it does not suit the theory of the interpreter. To MAX MÜLLER Achilles can be nothing but a solar god; for his imagination, fired with sunlight from the flaming east, can see nothing in the stout battles of Greeks and Trojans in the Iliad but the grand struggle between the powers of light and darkness. Of the probability of this theory I have sought in vain for the shadow of a proof. If Helen of Troy, whose name can obviously be identified with brightness (σέλας σελήνη), must on this account take her place with her brothers, as a sidereal phenomenon (sic *Fratres Helenæ*, LUCIDA SIDERA), this does seem to me an exceeding weak foundation for the transformation of the whole topographical and traditional heroes of the Iliad into a meteoric spectacle.

If, according to the views set forth in this paper, there is no scientific ground for raising Achilles into the category of gods, whether aquarian or solar, much stronger are the reasons which induce us, with unsophisticated old PLUTARCH, to see in Theseus no myth, but a great historical reality. If the principle be once accepted, that a single miraculous fact or incredible story connected in the popular imagination with a great popular name, shall deprive him *simpliciter* of all claim to a historical existence, we shall make strange havoc, I fear, with some of the most brilliant and the most instructive pages of national record. There is no need of believing all the wonderful stories that Athenian reverence and wonder accumulated round the name of Theseus, as little as there is of believing all the silly miracles that the Lausiac history narrates of the Egyptian ascetics; but there is certainly as little wisdom in roundly denying the historical germ to which, in all such cases, these accretions were attached.

I have thus pointed out, in a rapid and succinct way, what seem to be the

leading principles on which a sound and safe interpretation of early popular myths must proceed. I have kept myself purposely within the bounds of what appears to me sober statement, not being eager for the glory of adventure in this nebulous field; and if I shall seem to have achieved a very small thing when I keep myself within these bounds, I have at least kept myself clear of nonsense, which in mythological science is as common as sunk rocks in the Shetland seas. To MAX MÜLLER, and other Sanscrit scholars, I hope I shall always be grateful for any happy illustrations which they may supply of the general character of Aryan myths, and of occasional coincidences of the Hellenic mode of imagining with the Indian; and I think the somewhat cold and unimaginative race of English scholars are under no small obligations to him for having taught them to recognise poetical significance and religious value in some legends, which passed in their nomenclature for silly fables or worthless facts; but I profess to have been unable to derive any sure clue from the far East to the most difficult questions of Greek mythology; nor do I expect that, when every obsolete word in the Rigveda shall have been thoroughly sifted and shaken, a single ray of intelligible light will thence flow on the Athena of the Parthenon, or the Hermes of the Cyllenian slopes. I believe that in the region of mythology they will ultimately be found to be the wisest, who are at present content to know the least; that while some mythological fables are too trifling to deserve interpretation, others are too tangled to admit of it; and that the man who, at the present day, shall attempt to interpret the Greek gods from the transliteration of Sanscrit or Hebrew words, will be found, like Ixion, to have embraced a cloud for a goddess, and to have fathered a magnificent lie from the fruitful womb of his own conceit. There is no more dangerous passion than that which an ingenious mind conceives for the fine fancies which it begets.

III.—*On the Extension of Brouncker's Method to the Comparison of Several Magnitudes.* By Edward Sang, Esq.

(Read 7th February 1870.)

The discovery of those numbers which shall, either truly or approximately, represent the ratio of two magnitudes, necessarily attracted the attention of the earliest cultivators of exact science. The definition of the equality of ratios given in Euclid's compilation clearly exposes the nature of the process used in his time. This process consisted in repeating each of the two magnitudes until some multiple of the one agreed perfectly or nearly with a multiple of the other; the numbers of the repetitions, taken in inverse order, represented the ratio. Thus, if the proposed magnitudes were two straight lines, Euclid would have opened two pairs of compasses, one to each distance, and, beginning at some point in an indefinite straight line, he would step the two distances along, bringing up that which lagged behind, until he obtained an exact or a close coincidence.

He seems to have assumed that, in the case of incommensurable magnitudes, the further continuation of the process must give still closer approximations; but we do not find any indication of a knowledge of the fact that, in the course of that continuation, we shall certainly come upon coincidences still more close than any which we have already obtained.

This process for finding the numerical expression for a ratio is inconvenient from its bulkiness; it is also unnatural, for the mind, in comparing two unequal magnitudes, is rather inclined to regard them as made up each of so many measures, than to consider how many times the one must be augmented in order that the result may be a multiple of the other; it prefers the direct to the inverse comparison.

Lord Brouncker's method of continued fractions enables us with great rapidity and within the compass of the magnitudes themselves, to determine directly their ratio. It is one of the great landmarks in the progress of the science of numbers.

By one or two slight improvements in the mode of calculation, the *chain* or *continued fraction* became a ready tool in the hands of arithmeticians. It placed in a clear light the whole doctrine of indeterminate equations of the first degree, leaving scarcely anything further to be desired in this branch of the Diophantine analysis.

On applying BROUNCKER's method to two incommensurable quantities of the second degree, it was found that the denominators eventually came to be repeated or circulated indefinitely; and LAGRANGE showed that while every circulating chain-fraction was known to represent the root of a quadratic equation, the roots of all such equations were developable in such a fraction. Hence the conclusion was drawn that the root of no equation of a higher order can possibly be represented by a circulating chain-fraction.

Although, to the mind of BROUNCKER, the continued fraction presented the readiest way of expounding his idea, it is not essential thereto; a much clearer view of the true nature of the process may be obtained without it. The operation consists, essentially, in deducting, as often as possible, the less from the greater; the remainder again from the preceding subtrahend, and so on; in keeping note of the numbers of the subtractions; and in computing from these numbers the value of the magnitudes in terms of the ultimate subtrahend. The chain-fraction is merely one way of representing the final computation. By stopping at the first denominator, then at the second, afterwards at the third, and so on, we obtain a series of fractions alternately too great and too small, but approaching rapidly to each other and to the true expression for the ratio. Now this series may be deduced directly from the equations representing the various subtractions; wherefore, in our subsequent investigations, we may put the idea of the chain-fraction entirely aside, without thereby changing the intrinsic character of the Brounckerian process.

On examining the two series converging to the two roots of a quadratic equation, I observed that the circulating quotients are the same for both, but that their order is inverted. This observation led me to a singular law, which some years ago I submitted to the Society. It is this, that if we continue the formation of the series for one root beyond the non-circulating quotients, obliterate these and the fractions adjoining them, and then, using only the circulators, compute the series backwards, we shall obtain the other root of the equation; so that both roots are given by a, so to speak, two-headed progression.

The periodical recurrence of the quotients enables us to approximate as closely as may be desired to the roots of equations of the second order, with very little labour; and a kind of regret accompanied the conviction that the same facilities cannot be obtained for equations of higher degrees. On considering the arguments on which this conviction rested, it appeared to me that the whole circumstances of the case had not been taken into account; one, and a most influential one, had been concealed under the notation employed, that is, under the scheme of continued fractions. If we assume any two fractions to take the place of two contiguous terms in a Brounckerian progression, and operate upon these in the usual way, that is, by adding to a multiple of each member of the second fraction the corresponding member of the preceding; and

if we continue this operation, using always the same multiplier, or a circulating set of multipliers, the fractions so resulting converge to the root of a quadratic equation. If we should assume *three* fractions, and combine fixed multiples of their members, so as to form a progression of the third order, as we may call it, to what value do the terms of this progression converge?

In a paper read by me some time ago to the Society, it was shown that the convergence in this case is toward the root of a cubic equation; and that the same arrangement may be extended to the still higher orders; as examples of the application of this method, two cases may be cited.

If we begin with the two fractions $\frac{1}{0}, \frac{1}{1}$ and form a progression by adding to the double of each member of the last, the corresponding member of the preceding, we form the well-known progression

$$\frac{1}{0}, \frac{1}{1}, \frac{3}{2}, \frac{7}{5}, \frac{17}{12}, \frac{41}{29}, \frac{99}{70}, \text{ \&c.},$$

which converges toward the ratio of the diagonal to the side of a square.

If, beginning with the same pair, we form a progression by taking the sums of the members of the last and of the penult, we obtain

$$\frac{1}{0}, \frac{1}{1}, \frac{2}{1}, \frac{3}{2}, \frac{5}{3}, \frac{8}{5}, \frac{13}{8}, \frac{21}{13}, \frac{34}{21}, \text{ \&c.},$$

which converges toward the ratio of the diagonal of a regular pentagon to its side. In this case, the numerator of one fraction becomes the denominator of the succeeding, so that it is unnecessary to write both progressions. These are familiar examples of quadratic roots.

Let us now assume *three* terms, 0, 0, 1, and continue a progression by adding to the double of the last term the difference between the two previous ones, thus—

0, 0, 1, 2, 5, 11, 25, 56, 126, 283, 636, 1429, 3211, 7215, 16212, 36428, 81853, 183922, &c.,

and we obtain an approximation to the ratio of the long diagonal to the side of a regular heptagon. Thus, if the side of the heptagon be 283, its longest diagonal is almost exactly 636.

Or again if, assuming the same three terms 0, 0, 1, we form a series by deducting the antepenult from the triple of the last term, thus—

0, 0, 1, 3, 9, 26, 75, 216, 622, 1791, 5157, 14849, 42756, 123111, 354484, &c.,

we obtain an approximation to the ratio of the long diagonal of an enneagon to its side.

I have shown that, in progressions of this kind, that is, where the numerator

of the one fraction becomes the denominator of the other, the approximation is toward that root of the equation which is farthest from zero; and that if the progression be carried backwards, the approximation is then toward the root nearest to zero.

These remarks may suffice to show that this branch of the theory of numbers promises to yield important results. Now, the whole doctrine of quadratic recurrence sprung from the comparison of two magnitudes; and so the comparison of three magnitudes must be the true foundation on which to build the doctrine of cubic recurrence. I propose, therefore, in the present paper, to discuss the elementary operation by which the ratios of three incommensurable magnitudes may be approximately ascertained.

Let there be three homogeneous quantities, A, B, C, arranged in the order of their magnitudes, and let it be proposed, if possible, to find their common measure.

By repeatedly subtracting the second B from the greatest A, we obtain a remainder less than B; this remainder may or may not be greater than C; if it be greater, we may take C from it until we obtain a remainder D less than the least of the three proposed quantities. In this way we have an equation of the form

$$A = p_1 B + q_1 C + D,$$

in which p cannot be zero, while q may.

Treating now the three quantities B, C, D, in the same way we have a new equation

$$B = p_2 C + q_2 D + E,$$

and we may proceed in this way until there be no remainder, or until the remainder be so small as to pass the limits of exactitude demanded by the nature of the case in hand.

We are now able, by means of successive substitutions, to obtain values of A, B, C, in terms of the ultimate remainders; and our first business is to devise some convenient arrangement for this purpose.

For the sake of giving greater generality to our investigations, let us put the successive equations in the form

$$\begin{aligned} A &= p_1 B + q_1 C + r_1 D, \\ B &= p_2 C + q_2 D + r_2 E, \\ C &= p_3 D + q_3 E + r_3 F, \\ &\cdots\cdots\cdots\cdots \\ Q &= p_n R + q_n S + r_n T, \end{aligned}$$

in which r_1, r_2, ... have been written for the unit of the usual process.

By successive substitutions we arrive at a value of A, in terms of R, S, T, which may be conveniently represented by the equation,

$$A = \varphi n \,.\, R + \theta n \,.\, S + \psi n \,.\, T \ ,$$

and our business becomes to discover the law of formation of the functions φn, θn, ψn.

Continuing the operation one step further, we have

$$R = P_{n+1} \,.\, S + q_{n+1} \,.\, T + r_{n+1} \,.\, U \ ,$$

and substituting this value for R in the preceding equation,

$$A = \{p_{n+1} \,.\, \varphi n + \theta n\}\ S + \{q_{n+1} \,.\, \varphi n + \psi n\}\ T + r_{n+1} \,.\, \varphi n U \ ,$$

wherefore the law of successive formation is contained in the three equations—

$$\varphi(n+1) = p_{n+1} \,.\, \varphi n + \theta n \ , \quad . \quad . \quad . \quad (1),$$
$$\theta(n+1) = q_{n+1} \,.\, \varphi n + \psi n \ , \quad . \quad . \quad . \quad (2),$$
$$\psi(n+1) = r_{n+1} \,.\, \varphi n \ , \quad . \quad . \quad . \quad . \quad (3).$$

Now these forms hold good for every value of n, wherefore

$$\psi n = r_n \,.\, \varphi(n-1) \ ,$$

and consequently

$$\theta(n+1) = \varphi_{n+1} \,.\, \varphi n + r_n \,.\, \varphi(n-1) \ ,$$

whence

$$\theta n = q n \,.\, \varphi(n-1) + r_{n-1} \,.\, \varphi(n-2) \ ,$$

so that the equations (1), (2), (3) become

$$\varphi(n+1) = p_{n+1} \,.\, \varphi n + q_n \,.\, \varphi(n-1) + r_{n-1} \,.\, \varphi(n-2) \ , \quad (1),$$
$$\theta(n+1) = q_{n+1} \,.\, \varphi n + r_n \,.\, \varphi(n-1) \ , \quad . \quad . \quad . \quad . \quad (2),$$
$$\psi(n+1) = r_{n+1} \,.\, \varphi n \ , \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3).$$

By means of these formulæ we can construct the series of functions φn independently of the others, and thence we can readily deduce the progression θn; as for the third progression ψn it is, in the usual case of $r = 1$, a mere transcript of the progression φn moved one step back. The arrangement of the work is very simple, and may be best studied from a numerical example.

The arrangement of the intervals in music has to follow the natural subdivision of a vibrating column, and so must be made, primarily, to suit the ratios 1 : 2, 1 : 3, 1 : 5, and their compounds. If, then, it be proposed to tune a musical instrument so as to permit of transposition from one key to another, the ratio represented by the smallest interval on it must be contained exactly, or very nearly, in each of these three ratios. Therefore the arrangement of the gamut on an instrument of equable temperament must be obtained by a com-

parison of the logarithms of the three prime numbers 5, 3, and 2. These logarithms are incommensurable, and so it is impossible to tune a keyed instrument perfectly. The comparison of these three logarithms furnishes a convenient instance of the application of our method.

Putting, for shortness' sake, A = log 5, B = log 3, C = log 2, we obtain the following equations :—

$$
\begin{aligned}
\cdot 69897\ 00043 &= A = 1.B + 0.C + D \\
\cdot 47712\ 12547 &= B = 1.C + 0.D + E \\
\cdot 30102\ 99956 &= C = 1.D + 0.E + F \\
\cdot 22184\ 87496 &= D = 1.E + 0.F + G \\
\cdot 17609\ 12590 &= E = 2.F + 0.G + H \\
7918\ 12460 &= F = 1.G + 1.H + J \\
4575\ 74905 &= G = 2.H + 0.J + K \\
1772\ 87669 &= H = 1.J + 0.K + L \\
1569\ 49885 &= J = 1.K + 2.L + M \\
1029\ 99566 &= K = 5.L + 0.M + N \\
203\ 37784 &= L = 1.M + 5.N + P \\
132\ 74750 &= M = 10.N + 0.P + Q \\
13\ 10644 &= N = 2.P + 1.Q + R \\
5\ 09810 &= P \\
1\ 68303 &= Q \\
1\ 22720 &= R\ ;
\end{aligned}
$$

and, in order to compute from these the successive approximations, we may write the three sets of coefficients, p, q, r, in three horizontal lines, as in the subjoined scheme:—

r	1	1	1	1	1	1	1	1	1	1	1	1	1
q	0	0	0	0	0	1	0	0	2	0	5	0	1
p	1	1	1	1	2	1	2	1	1	5	1	10	2
A	1	1	1	2	3	7	9	28	35	44	318	353	5164	10638
B		1	1	1	2	5	6	19	24	30	217	241	3525	7267
C			1	1	1	3	4	12	15	19	137	152	2224	4585

Having written *unit* beneath the first p, to serve as the beginning of the series A, we multiply that unit by p_1 to get 1, the second value of A_2, which value we write beneath p_2. We now take the products $A_2\, p_2$, $A_1\, q_1$, the sum of which gives us $A_3 = 1$. Thereafter we take the sum of $A_3\, p_3$, $A_2\, q_2$, $A_1\, r_1$, to obtain $A_4 = 2$. In this example the first five q's happen to be zeroes, and so the middle terms of the expressions are awanting ; the middle term is first found in the expression for A_8, which is $A_7 . p_7 + A_6 . q_6 + A_5 . r_5 = 18 + 7 + 3$;

and again we have it in the value of A_{11}, which is $A_{10} \cdot p_{10} + A_9 \cdot q_9 + A_8 \cdot r_8 = 220 + 70 + 28$.

The series for B is formed exactly in the same way, only that its commencement is delayed one step ; in other words, B_1 is held as zero, and B_2 is made *unit.*

Similarly for C, C_1, C_2 are held as zeroes, and C_3 is made *unit.* We may in the same way find series for D, E, F, and so on.

The eighth set of values give 28, 19, 12 as nearly proportional to the logarithms of 5, 3, and 2. Assuming these as sufficiently near for the purposes of musicians, we must divide the interval corresponding to the ratio 1 : 2, called by them an *octave,* into 12 parts, to which the name semitone is given. In this way, counting in semitones, we have $\log 2 = 12$, $\log 3 = 19$, $\log 5 = 28$; whence $\log \frac{3}{2} = 7$, $\log \frac{5}{4} = 4$, and so on ; whence the arrangement of the gamut is at once obtained. According to these values, we should have $\log \frac{9}{8} = 2$, and $\log \frac{10}{9} = 2$, wherefore the degree of precision obtained by these numbers is not sufficient to discriminate between the tone major and the tone minor.

In order to obtain a closer approximation, we must proceed further along the series. Now it is important to keep to the nomenclature and arrangement of semitones ; wherefore we search among the series C for some member divisible by 12 ; no one of those above given is so divisible, and therefore we look for some compound of two of them which may be a multiple of 12. Thus $C_{10} + C_{11} = 156$, so that, still counting in semitones, we have $\log 5 = \frac{362}{13} = 27\frac{11}{13}$, $\log 3 = \frac{247}{13} = 19$, $\log 2 = \frac{156}{13} = 12$. From these values the logarithm of the tone major represented by the ratio $\frac{9}{8}$ is still 2, but that of the tone minor represented by $\frac{10}{9}$ is $1\frac{11}{13}$; in the same way the corrected values of the other musical intervals may be obtained.

By putting A, B, C to represent the periodic times of three astronomical phenomena, we may ascertain the intervals between their simultaneous recurrence. Thus, if we put A for the time of revolution of the moon's node, B and C for the earth's and moon's periodic times, we shall obtain directly the law of recurrence of eclipses.

If we take three contiguous sets of values, and thence compute the succeeding set, we obtain

$$\begin{aligned}
A_n \quad A_{n+1} \quad A_{n+2} \quad A_{n+3} &= p_{n+2} \cdot A_{n+2} + q_{n+1} \cdot A_{n+1} + r_n A_n \\
B_n \quad B_{n+1} \quad B_{n+2} \quad B_{n+3} &= p_{n+2} \cdot B_{n+2} + q_{n+1} \cdot B_{n+1} + r_n B_n \\
C_n \quad C_{n+1} \quad C_{n+2} \quad C_{n+3} &= p_{n+2} \cdot C_{n+2} + q_{n+1} \cdot C_{n+1} + r_n C_n ;
\end{aligned}$$

eliminating p and q from these three equations, we obtain, omitting the subscribed $_n$ for shortness,

$$r_n \{A_0 B_2 C_1 - A_0 B_1 C_2 + B_0 A_1 C_2 - B_0 A_2 C_1 + C_0 A_2 B_1 - C_0 A_1 B_2\} =$$
$$\{A_3 B_2 C_1 - A_3 B_1 C_2 + B_3 A_1 C_2 - B_3 A_2 C_1 + C_3 A_2 B_1 - C_3 A_1 B_2\}.$$

Now the first of these quantities within the ties is the determinant obtained from the coefficients

$$\begin{matrix} A_0 & A_1 & A_2 \\ B_0 & B_1 & B_2 \\ C_0 & C_1 & C_2 \end{matrix}$$

while the second is the determinant from the next three sets of values; or, using CAYLEY'S notation

$$r \begin{vmatrix} A_0 & A_1 & A_2 \\ B_0 & B_1 & B_2 \\ C_0 & C_1 & C_2 \end{vmatrix} = \begin{vmatrix} A_1 & A_2 & A_3 \\ B_1 & B_2 & B_3 \\ C_1 & C_2 & C_3 \end{vmatrix}$$

Now, in the usual operation, and when the three magnitudes are incommensurable, r is unit all along; wherefore the determinant from nine contiguous values never changes. But at the beginning this determinant is obviously unit, and thus we have the ordinary well-known theorem for the usual progression in reference to two magnitudes extended to the case of three; that is to say, the value of the determinant is + 1 all along. In the case of two magnitudes, the value is alternately + 1 and — 1; whereas, in the case of three magnitudes, the sign is preserved.

The above statement holds good in the case of incommensurable quantities; but when there is a common measure the quotient r may disappear toward the end of the operation, and then all the subsequent determinants become zero.

If, in the case of three commensurables, we complete the calculation, as in the following example in which the three primes 99137, 30763, and 3229 are compared, a remarkable yet obvious law is seen.

1	1	1	1	1	1	1				r
2	4	0	0	0	0	2	0			q
3	9	8	2	1	1	3	11	3		p
1	3	29	245	493	522	767	2794	32790	99137	A
	1	9	76	153	162	238	867	10175	30763	B
		1	8	16	17	25	91	1068	3229	C
			1	2	2	3	11	129	390	D
				1	1	1	4	47	142	E
					1	1	3	36	109	F
						1	3	35	106	G
							1	11	33	H
								1	3	I
									1	K

If we compare the last three values of A, which are in this case A_{10}, A_9, A_8; we observe that the order of the quotients must necessarily be, $A_{10} = p_9 A_9 + q_8 A_8 + r_7 A_7$; that is to say, the computation must take the form

1	1	1	1	1	1	1				
0	2	0	0	0	0	4	2			
3	11	3	1	1	2	8	9	3		
1	3	33	106	109	142	390	3229	30763	99137	*a*
	1	11	35	36	47	129	1068	10175	32790	*b*
		1	3	3	4	11	91	867	2794	*c*
			1	1	1	3	25	238	767	*d*
				1	1	2	17	162	522	*e*
					1	2	16	153	493	*f*
						1	8	76	245	*g*
							1	9	29	*h*
								1	3	*i*
									1	*k*

Hence, if the values of q were written above and between the contiguous values of p, and similarly with those of r, as in the subjoined scheme, the computation carried from left to right leads to the ultimate values of A, B, C; when carried from right to left it leads to those of A_n, A_{n-1}, and so on; but in each case it gives the same aggregate group of numbers; with a difference merely in position; and hence, whenever the numbers

		1		1		1		1		1		1		1			
	2		4		0		0		0		0		2		0		
3		9		8		2		1		1		3		11		3	

$p_0, p_1, p_2 \ldots\ldots, q_0, q_1, q_2, \ldots$, &c., are arranged symmetrically, the series of values $A_0, A_1, A_2 \ldots$ is identic with $A_1 B_1 C_1$ read inversely.

The continuation of the same process to the case of a greater number of magnitudes is so obvious as to stand in no need of farther illustration. The application of this process to problems involving the higher powers of numbers may be expected, as the Brounckerian process has already done for squares, to throw considerable light upon that difficult branch of the Theory of Numbers.

IV.—*On Green's and other Allied Theorems.* By Professor Tait.

(Received April 29th, read May 16th, 1870.)

I was originally attracted to the study of Quaternions by Sir W. R. Hamilton's ingeniously devised and most valuable operator

$$\nabla = i\frac{d}{dx} + j\frac{d}{dy} + k\frac{d}{dz},$$

to which he called special attention (*Lectures on Quaternions*, § 620) on account of its promise of usefulness in physical applications. But I soon found that in order that its full power may be applied, in general investigations, it is necessary that we should have processes of definite integration, of the kinds required in physics, applicable to quaternion symbols and not merely to scalar variables. I often consulted Hamilton about this want, and he promised to endeavour to supply it at some future time. I fancy that shortly before his death he must have in some way supplied it, though he certainly did not print, nor does he appear even to have written, anything on the subject. In one of the last letters I received from him, he said that he intended to conclude the final chapter of his *Elements*, which is devoted to physical applications, by some sections on the use of the operator mentioned above. That chapter remains unfinished, and as Hamilton rarely wrote down the steps of even a complex train of mathematical reasoning until he had mentally completed it, it is to be feared that this portion of his investigations is entirely lost. So far as the analytical aspect of Quaternions is concerned, this loss is very serious indeed, for there can be little doubt that Hamilton's solution would have been of immense value from the purely mathematical point of view.

I have recently succeeded to a certain extent, by a simple, though not very direct, process, in supplying the want—so far at least as to enable me to use quaternions in inquiries connected with potentials—and have thus arrived at very simple proofs of Green's celebrated theorem and various allied results, some of which appear to be new and valuable. The quaternion calculus can, in consequence, be applied without loss of its enormous special advantages to various general theories, such as Attractions, Spherical Harmonics, Fluid Motion, &c., &c. Curiously enough, I find that I had almost arrived at one of the general theorems given in the present paper so long ago as 1860 (*Quaternion Investigation of the Potential of a Closed Circuit, Quarterly Math. Journal*), but

though I then gave a special case I did not see that a very slight modification of my work would have enabled me to generalise it. I was then seeking to derive from my formulæ the well-known physical result, and not thinking of extending the calculus itself.

Even the little advance that I have made in the present paper has enabled me to see, with a thoroughness of comprehension which I had despaired of attaining (at least by Cartesian processes), the mutual relationship of the many singular properties of the great class of analytical and physical magnitudes which satisfy what is usually known as LAPLACE'S equation. This is, of course, solely due to the simplicity and expressiveness of quaternions in general.

1. In what follows we have constantly to deal with integrals extended over a closed surface, compared with others taken through the space enclosed by such a surface; or with integrals over a limited surface, compared with others taken round its bounding curve. The notation employed is as follows. If Q per unit of length, of surface, or of volume, at the point $x\ y\ z$, Q being any quaternion, be the quantity to be summed, these sums will be denoted by

$$\iint \mathrm{Q}ds \quad \text{and} \quad \iiint \mathrm{Q}d\varsigma,$$

when comparing integrals over a closed surface with others through the enclosed space; and by

$$\iint \mathrm{Q}ds \quad \text{and} \quad \int \mathrm{QT}d\rho,$$

when comparing integrals over an unclosed surface with others round its boundary. No ambiguity is likely to arise from the double use of

$$\iint \mathrm{Q}ds,$$

for its meaning in any case will be obvious from the integral with which it is compared.

2. I have already shown (*Proc. R.S.E.*, April 28th 1862,) that, if σ be the vector displacement of a point originally situated at

$$\rho = ix + jy + kz,$$

then

$$\mathrm{S}.\nabla\sigma$$

expresses the increase of density of aggregation of the points of the system caused by the displacement. (See *Appendix* to this paper.)

3. Suppose, now, space to be uniformly filled with points, and a closed surface Σ to be drawn, through which the points can freely move when displaced.

Then it is clear that the increase of number of points within the space Σ, caused by a displacement, may be obtained by either of two processes—by taking account of the increase of density at all points within Σ, or by estimating

the excess of those which pass inwards through the surface over those which pass outwards. These are the principles usually employed (for a mere element of volume) in forming the so-called "Equation of Continuity."

Let ν be the normal to Σ at the point ρ, drawn outwards, then we have at once (by equating the two different expressions of the same quantity above explained) the equation

$$\iiint \mathrm{S}.\nabla\sigma d\varsigma = \iint \mathrm{S}.\sigma \mathrm{U}\nu \, ds,$$

which is our fundamental equation so long as we deal with triple integrals.

4. As a first and very simple example of its use, suppose σ to represent the vector force exerted upon a unit particle at ρ (of ordinary matter, electricity, or magnetism) by any distribution of attracting matter, electricity, or magnetism partly outside, partly inside Σ. Then, if P be the potential at ρ,

$$\sigma = \nabla \mathrm{P},$$

and if r be the density of the attracting matter, &c., at ρ,

$$\nabla\sigma = \nabla^2 \mathrm{P} = 4\pi r$$

by Poisson's extension of Laplace's equation.

Substituting in the fundamental equation, we have

$$4\pi \iiint r d\varsigma = 4\pi \mathrm{M} = \iint \mathrm{S}.\nabla \mathrm{P} \mathrm{U}\nu \, ds,$$

where M denotes the whole quantity of matter, &c., inside Σ. This is a well-known theorem.

5. Let P and P_1 be any scalar functions of ρ, we can of course find the distribution of matter, &c., requisite to make either of them the potential at ρ: for, if the necessary densities be r and r_1 respectively, we have as before

$$\nabla^2 \mathrm{P} = 4\pi r, \quad \nabla^2 \mathrm{P}_1 = 4\pi r_1 .$$

Now

$$\nabla . \mathrm{P}\mathrm{P}_1 = \mathrm{P}\nabla \mathrm{P}_1 + \mathrm{P}_1 \nabla \mathrm{P},$$

and

$$\nabla^2 . \mathrm{P}\mathrm{P}_1 = \mathrm{P}\nabla^2 \mathrm{P}_1 + \mathrm{P}_1 \nabla^2 \mathrm{P} + 2\mathrm{S}.\nabla \mathrm{P} \nabla \mathrm{P}_1 .$$

But, by the fundamental theorem,

$$\iiint \nabla^2 . \mathrm{P}\mathrm{P}_1 d\varsigma = \iint \mathrm{S}.(\nabla . \mathrm{P}\mathrm{P}_1)\mathrm{U}\nu \, ds = \iint \mathrm{S}.(\mathrm{P}\nabla \mathrm{P}_1 + \mathrm{P}_1 \nabla \mathrm{P})\mathrm{U}\nu \, ds .$$

Substituting the above value of $\nabla^2 . \mathrm{P}\mathrm{P}_1$, this becomes

$$\iint \mathrm{S}.(\mathrm{P}\nabla \mathrm{P}_1 + \mathrm{P}_1 \nabla \mathrm{P})\mathrm{U}\nu \, ds = \iiint (\mathrm{P}\nabla^2 \mathrm{P}_1 + \mathrm{P}_1 \nabla^2 \mathrm{P}) d\varsigma + 2 \iiint \mathrm{S}.\nabla \mathrm{P} \nabla \mathrm{P}_1 d\varsigma .$$

But, obviously, we have also by the fundamental theorem

$$\iint \mathrm{S}.(\mathrm{P}\nabla \mathrm{P}_1 - \mathrm{P}_1 \nabla \mathrm{P})\mathrm{U}\nu \, ds = \iiint (\mathrm{P}\nabla^2 \mathrm{P}_1 - \mathrm{P}_1 \nabla^2 \mathrm{P}) d\varsigma ,$$

and the two latter equations give

$$\iiint \mathrm{S}.\nabla\mathrm{P}\nabla\mathrm{P}_1 d\varsigma = -\iiint \mathrm{P}_1\nabla^2\mathrm{P}\, d\varsigma + \iint \mathrm{P}_1\mathrm{S}.\nabla\mathrm{P}\mathrm{U}\nu\, ds\,,$$
$$= -\iiint \mathrm{P}\nabla^2\mathrm{P}_1 d\varsigma + \iint \mathrm{P}\mathrm{S}.\nabla\mathrm{P}_1\mathrm{U}\nu\, ds\,,$$

which are the common forms of GREEN's Theorem. Sir W. THOMSON's extension of it follows at once from the same proof.

6. If P_1 be a many-valued function, but $\nabla\mathrm{P}_1$ single-valued, and if Σ be a multiply-connected* space, the above expressions require a modification which was first shown to be necessary by HELMHOLTZ, and first supplied by THOMSON. For simplicity, suppose Σ to be doubly-connected (as a ring or endless rod, whether knotted or not). Then if it be cut through by a surface s, it will become simply-connected, but the surface-integrals have to be increased by terms depending upon the portions thus added to the whole surface. In the first form of GREEN's Theorem, just given, the only term altered is the last: and it is obvious that if p_1 be the increase of P_1 after a complete circuit of the ring, the portion to be added to the right hand side of the equation is

$$p_1 \iint \mathrm{S}.\nabla\mathrm{P}\mathrm{U}\nu\, ds$$

taken over the cutting surface only. Similar modifications are easily seen to be produced by each additional complexity in the space Σ.

7. The immediate consequences of GREEN's theorem are well known, so that I take only one instance.

Let P and P_1 be the potentials of one and the same distribution of matter, and let none of it be within Σ. Then we have

$$\iiint (\nabla\mathrm{P})^2 d\varsigma = \iint \mathrm{P}\mathrm{S}.\nabla\mathrm{P}\mathrm{U}\nu\, ds,$$

so that if $\nabla\mathrm{P}$ is zero all over the surface of Σ, it is zero all through the interior, *i.e.*, the potential is constant inside Σ. If P be the velocity-potential in the irrotational motion of an incompressible fluid, this equation shows that there can be no such motion of the fluid unless there is a normal motion at some part of the bounding surface, so long at least as Σ is simply-connected.

Again, if Σ is an equipotential surface,

$$\iiint (\nabla\mathrm{P})^2 d\varsigma = \mathrm{P}\iint \mathrm{S}.\nabla\mathrm{P}\mathrm{U}\nu\, ds = \mathrm{P}\iiint \nabla^2\mathrm{P}\, d\varsigma$$

by the fundamental theorem. But there is by hypothesis no matter inside Σ, so this shows that the potential is constant throughout the interior. Thus there can be no equipotential surface, not including some of the attracting matter, within which the potential can change. Thus it cannot have a maximum or minimum value at points unoccupied by matter.

* Called by HELMHOLTZ, after RIEMANN, *mehrfach zusammenhängend*. In translating HELMHOLTZ's paper (*Phil. Mag.* 1867) I used the above as an English equivalent. Sir W. THOMSON in his great paper on *Vortex Motion* (*Trans. R.S.E.* 1868) uses the expression "multiply-continuous."

8. If, in the fundamental theorem, we suppose

$$\sigma = \nabla\tau\,,$$

which imposes the condition that

$$\mathrm{S}.\nabla\sigma = 0\,,$$

i.e., that the σ displacement is effected without condensation, it becomes

$$\iint \mathrm{S}.\nabla\tau \mathrm{U}\nu ds = \iiint \mathrm{S}.\nabla^2\tau d\varsigma = 0\,.$$

Suppose any closed curve to be traced on the surface Σ, dividing it into two parts. This equation shows that the surface-integral is the same for both parts, the difference of sign being due to the fact that the normal is drawn in opposite directions on the two parts. Hence we see that, with the above limitation of the value of σ, the double integral is the same for all surfaces bounded by a given closed curve. It must therefore be expressible by a single integral taken round the curve. The value of this integral will presently be determined.

9. The theorem of § (4) may be written

$$\iiint \nabla^2 \mathrm{P} d\varsigma = \iint \mathrm{S}.\mathrm{U}\nu\nabla\mathrm{P} ds = \iint \mathrm{S}(\mathrm{U}\nu\nabla)\mathrm{P} ds\,.$$

From this we conclude at once that if

$$\sigma = i\mathrm{P} + j\mathrm{P}_1 + k\mathrm{P}_2\,,$$

(which may, of course, represent any vector whatever) we have

$$\iiint \nabla^2\sigma d\varsigma = \iint \mathrm{S}(\mathrm{U}\nu\nabla)\sigma ds\,,$$

or, if

$$\nabla^2\sigma = \tau\,,$$

$$\iiint \tau d\varsigma = \iint \mathrm{S}(\mathrm{U}\nu\nabla^{-1})\tau\, ds\,.$$

This gives us the means of representing, by a surface-integral, a vector-integral taken through a definite space. We have already seen how to do the same for a scalar-integral—so that we can now express in this way, subject, however, to an ambiguity presently to be mentioned, the general integral

$$\iiint q d\varsigma\,,$$

where q is any quaternion whatever. It is evident that it is only in certain classes of cases that we can *expect* a perfectly definite expression of such a volume-integral in terms of a surface-integral.

10. In the above formula for a vector-integral there may present itself an ambiguity introduced by the inverse operation

$$\nabla^{-1}$$

to which we must devote a few words. The assumption

$$\nabla^2\sigma = \tau$$

is tantamount to saying that, as the constituents of σ are the potentials of certain distributions of matter, &c., those of τ are the corresponding densities each multiplied by 4π.

If, therefore, τ be given throughout the space enclosed by Σ, σ is given by this equation *so far only* as it depends upon the distribution within Σ, and must be completed by an arbitrary vector depending on *three* potentials of mutually independent distributions exterior to Σ.

But, if σ be given, τ is perfectly definite; and as

$$\nabla\sigma = \nabla^{-1}\tau\,,$$

the value of ∇^{-1} is also completely defined. These remarks must be carefully attended to in using the theorem above: since they involve as particular cases of their application many curious theorems in Fluid Motion, &c. To these, however, I shall not further allude here, as I propose to make them the subject of a separate communication to the Society.

11. We now come to relations between the results of integration extended over a non-closed surface and round its boundary.

Let σ be any vector function of the position of a point. The line-integral whose value we seek as a fundamental theorem is

$$\int \mathrm{S}.\sigma d\tau,$$

where τ is the vector of any point in a small closed curve, drawn from a point within it, and in its plane.

Let σ_0 be the value of σ at the origin of τ, then

$$\sigma = \sigma_0 - \mathrm{S}(\tau\nabla)\sigma_0$$

(*Proc. R.S.E.*, 28th April 1862; see also *Appendix* to this paper), so that

$$\int \mathrm{S}.\sigma d\tau = \int \mathrm{S}.(\sigma_0 - \mathrm{S}(\tau\nabla)\sigma_0)d\tau\,.$$

But

$$\int d\tau = 0\,,$$

because the curve is closed; and (Tait on *Electro-Dynamics*, § 13, *Quarterly Math. Journal*, Jan. 1860) we have generally

$$\int \mathrm{S}.\tau\nabla\,\mathrm{S}.\sigma_0 d\tau = \tfrac{1}{2}\mathrm{S}.\nabla(\tau\mathrm{S}\sigma_0\tau - \sigma_0\int \mathrm{V}.\tau d\tau)\,.$$

Here the integrated part vanishes for a closed circuit, and

$$\tfrac{1}{2}\int \mathrm{V}.\tau d\tau = ds\,\mathrm{U}\nu\,,$$

where ds is the area of the small closed curve, and $\mathrm{U}\nu$ is a unit-vector perpendicular to its plane. Hence

$$\int \mathrm{S}.\sigma_0 d\tau = \mathrm{S}.\nabla\sigma_0\mathrm{U}\nu.ds\,.$$

Now, any finite portion of a surface may be broken up into small elements such as we have just treated, and the sign only of the integral along each portion of a bounding curve is changed when we go round it in the opposite direction. Hence, just as AMPÈRE did with electric currents, substituting for a finite closed circuit a network of an infinite number of infinitely small ones, in each contiguous pair of which the common boundary is described by equal currents in opposite directions, we have for a finite unclosed surface

$$\int \mathrm{S}.\sigma d\rho = \iint \mathrm{S}.\nabla\sigma \mathrm{U}\nu.ds\,.$$

There is no difficulty in extending this result to cases in which the bounding curve consists of detached ovals, or possesses multiple points. This theorem seems to have been first given by THOMSON (THOMSON & TAIT'S "Natural Philosophy," § 190 (*j*); THOMSON on *Vortex Motion, Trans. R.S.E.*, 1868–9, § 60 (*q*)), where it has the form

$$\int(\alpha dx + \beta dy + \gamma dz) = \iint ds\left(l\left(\frac{d\gamma}{dy} - \frac{d\beta}{dz}\right) + m\left(\frac{d\alpha}{dz} - \frac{d\gamma}{dx}\right) + n\left(\frac{d\beta}{dx} - \frac{d\alpha}{dy}\right)\right).$$

It solves the problem suggested by the result of § 8 above.

12. If σ represent the vector force acting on a particle of matter at ρ, $-\mathrm{S}.\sigma d\rho$ represents the work done while the particle is displaced along $d\rho$, so that the single integral

$$\int \mathrm{S}.\sigma d\rho$$

of last section, taken with a negative sign, represents the work done during a complete cycle. When this integral vanishes it is evident that, if the path be divided into any two parts, the work spent during the particle's motion through one part is equal to that gained in the other. Hence the system of forces must be conservative, *i.e.*, must do the same amount of work for all paths having the same extremities.

But the equivalent double integral must also vanish. Hence a conservative system is such that

$$\iint ds\,\mathrm{S}\,.\,\nabla\sigma \mathrm{U}\nu = 0\,,$$

whatever be the form of the finite portion of surface of which ds is an element. Hence, as $\nabla\sigma$ has a fixed value at each point of space, while $\mathrm{U}\nu$ may be altered at will, we must have

$$\mathrm{V}\,\nabla\sigma = 0\,,$$

or

$$\nabla\sigma = \text{scalar}.$$

If we call X, Y, Z the component forces parallel to rectangular axes, this extremely simple equation is equivalent to the well-known conditions

$$\frac{d\mathrm{X}}{dy} - \frac{d\mathrm{Y}}{dx} = 0\,,\ \frac{d\mathrm{Y}}{dz} - \frac{d\mathrm{Z}}{dy} = 0\,,\ \frac{d\mathrm{Z}}{dx} - \frac{d\mathrm{X}}{dz} = 0\,.$$

Returning to the quaternion form, as far less complex, we see that

$$\nabla\sigma = \text{scalar} = 4\pi r, \text{ suppose,}$$

implies that

$$\sigma = \nabla \mathrm{P},$$

where P is a scalar such that

$$\nabla^2 \mathrm{P} = 4\pi r;$$

that is, P is the potential of a distribution of matter, magnetism, or statical electricity, of volume-density r.

Hence, for a non-closed path, under conservative forces

$$\begin{aligned} -\int \mathrm{S}.\sigma d\rho &= -\int \mathrm{S}.\nabla \mathrm{P} d\rho \\ &= -\int \mathrm{S}(d\rho\nabla)\mathrm{P} \\ &= \int d_{d\rho}\mathrm{P} = \int d\mathrm{P} \text{ (see } \textit{Appendix}) \\ &= \mathrm{P}_1 - \mathrm{P}_0, \end{aligned}$$

depending solely on the values of P at the extremities of the path.

13. A Vector theorem, which is of great use, and which corresponds to the Scalar theorem of § 11, may easily be obtained. Thus, with the notation already employed,

$$\begin{aligned} \int \mathrm{V}.\sigma d\tau &= \int \mathrm{V}(\sigma_0 - \mathrm{S}(\tau\nabla)\sigma_0) d\tau, \\ &= -\int \mathrm{S}(\tau\nabla)\mathrm{V}.\sigma_0 d\tau. \end{aligned}$$

Now

$$\mathrm{V}(\mathrm{V}.\nabla\mathrm{V}.\tau d\tau)\sigma_0 = -\mathrm{S}(\tau\nabla)\mathrm{V}.\sigma_0 d\tau - \mathrm{S}(d\tau\nabla)\mathrm{V}\tau\sigma_0,$$

and

$$d(\mathrm{S}(\tau\nabla)\mathrm{V}\sigma_0\tau) = \mathrm{S}(\tau\nabla)\mathrm{V}.\sigma_0 d\tau + \mathrm{S}(d\tau\nabla)\mathrm{V}\sigma_0\tau.$$

Subtracting, and omitting the term which is the same at both limits, we have

$$\int \mathrm{V}.\sigma d\tau = \mathrm{V}.(\mathrm{V}.\mathrm{U}\nu\nabla)\sigma_0 ds.$$

Extended as above to any closed curve, this takes at once the form

$$\int \mathrm{V}.\sigma d\rho = \iint ds \mathrm{V}.(\mathrm{V}.\mathrm{U}\nu\nabla)\sigma.$$

Of course, in many cases of the attempted representation of a quaternion surface-integral by another taken round its bounding curve, we are met by ambiguities as in the case of the space-integral (§ 9): but their origin, both analytically and physically, is in general obvious.

14. If P be any scalar function of ρ, we have (by the process of § 11, above)

$$\begin{aligned} \int \mathrm{P} d\tau &= \int (\mathrm{P}_0 - \mathrm{S}(\tau\nabla)\mathrm{P}_0) d\tau \\ &= -\int \mathrm{S}.\tau\nabla\mathrm{P}_0.d\tau. \end{aligned}$$

But

$$\mathrm{V}.\nabla\mathrm{V}.\tau d\tau = d\tau\mathrm{S}.\tau\nabla - \tau\mathrm{S}.d\tau\nabla\,,$$

and

$$d(\tau\mathrm{S}\tau\nabla) = d\tau\mathrm{S}.\tau\nabla + \tau\mathrm{S}.d\tau\nabla\,.$$

These give

$$\int \mathrm{P}d\tau = -\tfrac{1}{2}(\tau\mathrm{S}\tau\nabla - \mathrm{V}.\mathrm{V}\tau d\tau\nabla)\mathrm{P}_0 = ds\mathrm{V}.\mathrm{U}\nu\nabla\mathrm{P}_0\,.$$

Hence, for a closed curve of any form, we have

$$\int \mathrm{P}d\rho = \iint ds\mathrm{V}.\mathrm{U}\nu\nabla\mathrm{P}\,,$$

from which the theorems of §§ 11, 13 may easily be deduced.

15. The above are but a few of the simpler of an immense host of theorems which any one with some knowledge of quaternions may easily work out for himself, by developing a little farther, or applying to other combinations, the processes just explained. I shall, therefore, give no more of them until I have an opportunity of, at the same time, showing their ready applicability and great value in physical investigations.

Appendix, added June 3d 1870.

16. At the instance of Prof. KELLAND, to whom this paper was referred, I append a slight sketch of some of the properties of the operator ∇, of which so much use has been made in the foregoing paragraphs. Most of the results now to be given have been already published by myself, but the mode in which they were formerly deduced has been abandoned for one more purely quaternionic.

17. It may perhaps be useful to commence with a different form of definition of the operator ∇, as we shall thus, if we desire it, entirely avoid the use of ordinary Cartesian co-ordinates. For this purpose we write

$$\mathrm{S}\,.\,\alpha\nabla = -\,d_\alpha\,,$$

where α is any unit-vector, the meaning of the right hand operator (neglecting its sign) being the *rate of change of the function to which it is applied* per unit of length in the direction of the unit-vector α. If α be not a unit-vector we may treat it as a vector-velocity, and then the right hand operator means the *rate of change per unit of time* due to the change of position.

Let α, β, γ be any rectangular system of unit-vectors, then by a fundamental quaternion transformation

$$\nabla = -\,\alpha\mathrm{S}\alpha\nabla - \beta\mathrm{S}\beta\nabla - \gamma\mathrm{S}\gamma\nabla = \alpha d_\alpha + \beta d_\beta + \gamma d_\gamma$$

which is identical with HAMILTON'S form given above. (*Lectures*, § 620.)

18. This mode of viewing the subject enables us to see at once that the effect

of applying ∇ to any scalar function of the position of a point is to give its *vector of most rapid increase.* Hence, when it is applied to a potential u, we have

$$\nabla u = \text{vector-force at } \rho.$$

If u be a velocity-potential, we obtain the velocity of the fluid element at ρ; and if u be the temperature of a conducting solid we obtain the flux of heat. Finally, whatever series of surfaces is represented by

$$u = \mathrm{C},$$

the vector ∇u is the normal at the point ρ, and its length is inversely as the normal distance at that point between two consecutive surfaces of the series.

Hence it is evident that

$$\mathrm{S}.d\rho\nabla u = -du,$$

or, as it may be written,

$$-\mathrm{S}.d\rho\nabla = d;$$

the left hand member therefore expresses total differentiation in virtue of any arbitrary, but small, displacement $d\rho$.

19. To interpret the operator $\mathrm{V}.\alpha\nabla$ let us apply it to a potential function u. Then we easily see that u may be taken under the vector sign, and the expression

$$\mathrm{V}(\alpha\nabla)u = \mathrm{V}.\alpha\nabla u$$

denotes the vector-couple due to the force at ρ about a point whose relative vector is α.

Again, if σ be any vector function of ρ, we have by ordinary quaternion operations

$$\mathrm{V}(\alpha\nabla).\sigma = \mathrm{S}.\alpha\mathrm{V}\nabla\sigma + \alpha\mathrm{S}\nabla\sigma - \nabla\mathrm{S}\alpha\sigma.$$

The meaning of the third term (in which it is of course understood that ∇ operates on σ alone) is obvious from what precedes. It remains that we explain the other terms.

20. These involve the very important quantities (not *operators* such as the expressions we have been hitherto considering),

$$\mathrm{S}.\nabla\sigma \text{ and } \mathrm{V}.\nabla\sigma,$$

which occur very frequently in the preceding paper. There we looked upon σ as the displacement, or as the velocity, of a point situated at ρ. Let us now consider the group of points situated near to that at ρ, as the quantities to be interpreted have reference to the deformation of the group.

21. Let τ be the vector of one of the group relative to that situated at ρ.

Then after a small interval of time t, the actual co-ordinates become

$$\rho + t\sigma$$

and

$$\rho + \tau + t(\sigma - \mathrm{S}(\tau\nabla)\sigma)$$

by the definition of ∇ in § 17. Hence, if φ be the linear and vector function representing the deformation of the group, we have

$$\varphi\tau = \tau - t\mathrm{S}(\tau\nabla)\sigma .$$

The farther solution is rendered very simple by the fact that we may assume t to be so small that its square and higher powers may be neglected.

If φ' be the function conjugate to φ, we have

$$\varphi'\tau = \tau - t\nabla\mathrm{S}\tau\sigma .$$

Hence

$$\varphi\tau = \tfrac{1}{2}(\varphi + \varphi')\tau + \tfrac{1}{2}(\varphi - \varphi')\tau$$

$$= \tau - \frac{t}{2}\Big[\mathrm{S}(\tau\nabla)\sigma + \nabla\mathrm{S}\tau\sigma\Big] - \frac{t}{2}\mathrm{V}.\tau\mathrm{V}\nabla\sigma .$$

The first three terms form a self-conjugate linear and vector function of τ, which we may denote for a moment by $\varpi\tau$. Hence

$$\varphi\tau = \varpi\tau - \frac{t}{2}\mathrm{V}.\tau\mathrm{V}\nabla\sigma ,$$

or, omitting t^2 as above,

$$\varphi\tau = \varpi\tau - \frac{t}{2}\mathrm{V}.\varpi\tau\mathrm{V}\nabla\sigma .$$

Hence the deformation may be decomposed into—1st, the pure strain ϖ, 2d, the rotation

$$\frac{t}{2}\mathrm{V}\nabla\sigma .$$

Thus the *vector-axis of rotation of the group* is

$$\tfrac{1}{2}\mathrm{V}\nabla\sigma .$$

If we were content to avail ourselves of the ordinary results of Cartesian investigations, we might at once have reached this conclusion by noticing that

$$\mathrm{V}\nabla\sigma = i\left(\frac{d\zeta}{dy} - \frac{d\eta}{dz}\right) + j\left(\frac{d\xi}{dz} - \frac{d\zeta}{dx}\right) + k\left(\frac{d\eta}{dx} - \frac{d\xi}{dy}\right) ,$$

and remembering the formulæ of Stokes and Helmholtz.

22. In the same way, as

$$\mathrm{S}\nabla\sigma = -\frac{d\xi}{dx} - \frac{d\eta}{dy} - \frac{d\zeta}{dz} ,$$

we recognise the *cubical compression* of the group of points considered. It would be easy to give this a more strictly quaternionic form by employing the definition of § 17. But, working with quaternions, we ought to obtain all our results by their help alone; so that we proceed to prove the above result by

finding the volume of the ellipsoid into which an originally spherical group of points has been distorted in time t.

For this purpose, we refer again to the equation of deformation

$$\varphi\tau = \tau - t\mathrm{S}(\tau\nabla)\sigma\,,$$

and form the cubic in φ according to HAMILTON's exquisite process. We easily obtain, remembering that t^2 is to be neglected,*

$$0 = \varphi^3 - (3 - t\mathrm{S}\nabla\sigma)\varphi^2 + (3 - 2t\mathrm{S}\nabla\sigma)\varphi - (1 - t\mathrm{S}\nabla\sigma)\,,$$

or

$$0 = (\varphi - 1)^2(\varphi - 1 + t\mathrm{S}\nabla\sigma)\,.$$

The roots of this equation are the ratios of the diameters of the ellipsoid whose directions are unchanged to that of the sphere. Hence the volume is increased by the factor

$$1 - t\mathrm{S}\nabla\sigma\,,$$

from which the truth of the preceding statement is manifest.

23. As the process in last section depends essentially on the use of a non-conjugate vector function, with which the reader is less likely to be acquainted than with the more usually employed forms, I add another investigation.

Let

$$\varpi = \varphi\tau = \tau - t\mathrm{S}(\tau\nabla)\sigma\,.$$

Then

$$\tau = \varphi^{-1}\varpi = \varpi + t\mathrm{S}(\varpi\nabla)\sigma\,.$$

Hence since if, before distortion, the group formed a sphere of radius 1, we have

$$\mathrm{T}\tau = 1\,,$$

* Thus, in HAMILTON's notation, λ, μ, ν being any three non-coplanar vectors, and m, m_1, m_2 the coefficients of the cubic,

$$\begin{aligned}
-m\mathrm{S}.\lambda\mu\nu &= \mathrm{S}.\varphi'\lambda\varphi'\mu\varphi'\nu \\
&= \mathrm{S}.(\lambda - t\nabla\mathrm{S}\lambda\sigma)(\mu - t\nabla\mathrm{S}\mu\sigma)(\nu - t\nabla\mathrm{S}\nu\sigma) \\
&= \mathrm{S}.(\lambda - t\nabla\mathrm{S}\lambda\sigma)(\mathrm{V}\mu\nu - t\mathrm{V}\mu\nabla\mathrm{S}\nu\sigma + t\mathrm{V}\nu\nabla\mathrm{S}\mu\sigma) \\
&= \mathrm{S}.\lambda\mu\nu - t[\mathrm{S}.\mu\nu\nabla\mathrm{S}\lambda\sigma + \mathrm{S}.\nu\lambda\nabla\mathrm{S}\mu\sigma + \mathrm{S}.\lambda\mu\nabla\mathrm{S}\nu\sigma] \\
&= \mathrm{S}.\lambda\mu\nu - t\mathrm{S}.[\lambda\mathrm{S}.\mu\nu\nabla + \mu\mathrm{S}.\nu\lambda\nabla + \nu\mathrm{S}.\lambda\mu\nabla]\sigma \\
&= \mathrm{S}.\lambda\mu\nu - t\mathrm{S}.\lambda\mu\nu\mathrm{S}\nabla\sigma\,. \\
m_1\mathrm{S}.\lambda\mu\nu &= \mathrm{S}.\lambda\varphi'\mu\varphi'\nu + \mathrm{S}.\mu\varphi'\nu\varphi'\lambda + \mathrm{S}.\nu\varphi'\lambda\varphi'\mu \\
&= \mathrm{S}.\lambda(\mathrm{V}\mu\nu - t\mathrm{V}\mu\nabla\mathrm{S}\nu\sigma + t\mathrm{V}\nu\nabla\mathrm{S}\mu\sigma) + \&\mathrm{c}. \\
&= \mathrm{S}.\lambda\mu\nu - t\mathrm{S}.\lambda\mu\nabla\mathrm{S}\nu\sigma - t\mathrm{S}.\nu\lambda\nabla\mathrm{S}\mu\sigma + \&\mathrm{c}. \\
&= 3\mathrm{S}.\lambda\mu\nu - 2t\mathrm{S}\nabla\sigma\mathrm{S}.\lambda\mu\nu. \\
-m_2\mathrm{S}.\lambda\mu\nu &= \mathrm{S}.\lambda\mu\varphi'\nu + \mathrm{S}.\mu\nu\varphi'\lambda + \mathrm{S}.\nu\lambda\varphi'\mu \\
&= \mathrm{S}.\lambda\mu\nu - t\mathrm{S}.\lambda\mu\nabla\mathrm{S}\nu\sigma + \&\mathrm{c}. \\
&= 3\mathrm{S}.\lambda\mu\nu - t\mathrm{S}\nabla\sigma\mathrm{S}.\lambda\mu\nu.
\end{aligned}$$

the equation of the ellipsoid is

$$\mathrm{T}(\varpi + t\mathrm{S}(\varpi\nabla)\sigma) = 1\,,$$

or

$$\varpi^2 + 2t\mathrm{S}\varpi\nabla\mathrm{S}\varpi\sigma = -1\,.$$

This may be written

$$\mathrm{S}.\varpi\chi\varpi = \mathrm{S}.\varpi(\varpi + t\nabla\mathrm{S}\varpi\sigma + t\mathrm{S}(\varpi\nabla)\sigma) = -1\,,$$

where χ is now self-conjugate.

Hamilton has shown that the reciprocal of the product of the squares of the semiaxes is

$$-\mathrm{S}.\chi i\chi j\chi k\,,$$

whatever rectangular system of unit-vectors is denoted by i, j, k.

Substituting the value of χ, we have

$$\begin{aligned}
&-\mathrm{S}.(i + t\nabla\mathrm{S}i\sigma + t\mathrm{S}(i\nabla)\sigma)(j + \&c.)(k + \&c.)\\
&= -\mathrm{S}.(i + t\nabla\mathrm{S}i\sigma + t\mathrm{S}(i\nabla)\sigma)(i + 2ti\mathrm{S}\nabla\sigma - t\mathrm{S}(i\nabla)\sigma - t\nabla\mathrm{S}i\sigma)\\
&= \quad 1 + 2t\mathrm{S}\nabla\sigma\,.
\end{aligned}$$

The ratio of volumes of the ellipsoid and sphere is therefore, as before,

$$\frac{1}{\sqrt{1 + 2t\mathrm{S}\nabla\sigma}} = 1 - t\mathrm{S}\nabla\sigma\,.$$

24. Before concluding I may append a generalised form of Green's Theorem, which is obviously fitted to be of use in quaternion investigations. If we put

$$\tau = i\mathrm{P} + j\mathrm{P}' + k\mathrm{P}'',$$

we easily see by the equations at the end of § 5 that

$$\begin{aligned}
\iiint \mathrm{S}(\nabla\mathrm{P}_1.\nabla)\tau ds_3 &= -\iiint \mathrm{P}_1\nabla^2\tau ds_3 + \iint \mathrm{P}_1\mathrm{S}(\mathrm{U}\nu.\nabla)\tau ds\,,\\
&= -\iiint \tau\nabla^2\mathrm{P}_1 ds_3 + \iint \tau\mathrm{S}.\nabla\mathrm{P}_1\mathrm{U}\nu.ds\,.
\end{aligned}$$

As a particular case, let

$$\mathrm{P}_1 = \mathrm{S}\alpha\rho$$

so that

$$\begin{aligned}
\nabla\mathrm{P}_1 &= i\mathrm{S}i\alpha + j\mathrm{S}j\alpha + k\mathrm{S}k\alpha = -\alpha\,,\\
\nabla^2\mathrm{P}_1 &= 0\,,
\end{aligned}$$

we have

$$\begin{aligned}
\iiint \mathrm{S}(\alpha\nabla)\tau ds_3 &= \iiint \mathrm{S}\alpha\rho\nabla^2\tau ds_3 - \iint \mathrm{S}\alpha\rho\mathrm{S}(\mathrm{U}\nu\nabla)\tau ds\,,\\
&= \iint \tau\mathrm{S}.\alpha\mathrm{U}\nu\, ds\,.
\end{aligned}$$

Any constant may be added to the value of P_1. The additional terms thus introduced must vanish. This gives, as in § 9,

$$\iiint \nabla^2 \tau d\varsigma = \iint S(U\nu\nabla)\tau ds .$$

As another verification, suppose τ constant, and we have

$$\iint S.\alpha U\nu \, ds = 0 ,$$

which is obviously true. Interesting results are obtained by treating this by the processes of §§ 8, 11.

25. From one of the theorems above—viz.,

$$\iiint S(\alpha\nabla)\tau d\varsigma = \iint \tau S.\alpha U\nu \, ds ,$$

we have by the formula of § 17

$$\iiint \nabla\tau d\varsigma = \iint U\nu.\tau \, ds ,$$

a considerable extension of the fundamental theorem of § 3, which is, in fact, only its scalar part. It might have been obtained, however, as the reader will easily see, by a much more direct process. The vector part

$$\iiint V\nabla\tau \, d\varsigma = \iint VU\nu.\tau \, ds ,$$

as we see by the meaning of $V\nabla\tau$ in § 21, is of great importance in physical applications, especially in connection with Electricity and with Fluid Motion. When

$$\tau = \nabla P ,$$

where P is is a scalar, the left hand member vanishes, and the value of the right hand member limited to a non-closed surface is then found as in § 14.

26. Again, let

$$P_1 = \rho^2 ,$$

which gives

$$\nabla P_1 = -2\rho ,$$
$$\nabla^2 P_1 = 6 .$$

We have

$$\begin{aligned} -2\iiint S(\rho\nabla)\tau d\varsigma &= -\iiint \rho^2\nabla^2\tau d\varsigma + \iint \rho^2 S(U\nu\nabla)\tau ds \\ &= -6\iiint \tau d\varsigma - 2\iint \tau S.\rho U\nu \, ds . \end{aligned}$$

Now if the constituents of τ be homogeneous functions of ρ of the nth degree, we have for any one of them

$$S.\rho\nabla\xi = -n\xi ,$$

so that under these circumstances

$$(n+3)\iiint \tau d\varsigma = -\iint \tau S.\rho U\nu \, ds .$$

Of this a particular case is

$$(n + 3)\iiint \xi d\varsigma = -\iint \xi \mathrm{S}.\rho \mathrm{U}\nu \, ds,$$

which suggests many curious theorems.

27. As a verification of it, let the closed surface Σ which determines the limits of the integrations be itself

$$\xi = \mathrm{C},$$

which, of course, subjects the form of ξ to further limitations.

The right hand member is obviously equal to

$$3\mathrm{C} \times \text{vol. of } \Sigma,$$

because $-\mathrm{S}.\rho\mathrm{U}\nu$ is the perpendicular from the origin to the tangent plane at ρ to the element ds. The left hand side may be broken up into a set of shells bounded by surfaces whose equations are

$$\xi = e^n \mathrm{C},$$

where e varies from 0 to 1. [This follows from the assumption that ξ is homogeneous.] The volume of the surface corresponding to any value of e is obviously

$$e^3 \times \text{vol. of } \Sigma.$$

Hence

$$d\varsigma = 3e^2 de \times \text{vol. of } \Sigma,$$

so that the left-hand member of the equation above becomes

$$(n + 3)\int_0^1 3\mathrm{C}e^{n+2} de \times \text{vol. of } \Sigma = 3\mathrm{C} \times \text{vol. of } \Sigma,$$

and the proposition is proved.

28. A very interesting case is when

$$\xi = \frac{1}{\mathrm{T}\rho^3},$$

in which case $n = -3$, and our equation appears to become

$$(3 - 3)\iiint \frac{d\varsigma}{\mathrm{T}\rho^3} = 0 = -\iint \mathrm{S}.\frac{\mathrm{U}\rho}{\mathrm{T}\rho^2}\mathrm{U}\nu \, ds.$$

It is obvious, however, that there is an infinite element on the left hand, when $\mathrm{T}\rho = 0$, *i.e.*, when the origin lies inside Σ; and it is easy to see that the correct result is a simple case of the well-known equation of § 4. In fact, the expression on the right denotes, as is evident, the whole spherical opening subtended at the origin by Σ. Its value is therefore 0 if the origin be without Σ, and 4π if within—Σ being supposed to be simply-connected.

29. As a final example let us suppose in § 26 that ξ is a Spherical Harmonic.

Then, in addition to the condition of homogeneity there given, we have the condition

$$\nabla^2 \xi = 0 ,$$

and the general equation of the section referred to gives

$$2n \iiint \xi d\varsigma = \iint \rho^2 \mathrm{S.U}\nu \nabla \xi \, ds ,$$

so that, with the help of the final equation of § 26 we have for any closed surface whatever

$$\iint \mathrm{S.U}\nu (2n\rho\xi + \overline{n+3}\rho^2 \nabla \xi) ds = 0 .$$

This integral, whose value is obviously the same for all surfaces bounded by a given closed curve, can be reduced to the form

$$\iint (\mathrm{T}\rho)^{\frac{4n+6}{n+3}} \mathrm{S.U}\nu \nabla \left(q_0 - \frac{\xi}{(\mathrm{T}\rho)^{\frac{2n}{n+3}}} \right) ds ,$$

where q_0 is any quaternion which satisfies the condition

$$\nabla q_0 = 0 .$$

This is susceptible of various remarkable transformations, both as a double and as a single integral. But this digression might be indefinitely extended, and perhaps has already gone too far.

30. The essential basis of the whole of this theory is the great invention of HAMILTON, by which it is made possible to represent as a vector-operator the square root of LAPLACE'S operator

$$-\frac{d^2}{dx^2} - \frac{d^2}{dy^2} - \frac{d^2}{dz^2} ,$$

which has not yet been done by any but quaternion symbols, at least in a symmetrical, easily intelligible, and practically useful form.

It is rash to make any definite assertions on such matters, especially when a writer of such extraordinary fertility, knowledge, and power as Sir W. R. HAMILTON is concerned, but to the best of my knowledge the greater part of the results given above is my own. HAMILTON'S treatment of ∇, so far as I am aware of its having been published, will be found in *Proc. R.I.A.*, 1846 and 1854, (in the latter of which there is a very curious and interesting proof of DUPIN'S Theorem,) and in his *Lectures on Quaternions*, § 620. My own is to be found in *Quarterly Math. Journal*, October 1860; *Proc. R.S.E.*, 1861–2, 1862–3; and *Elementary Treatise on Quaternions*, §§ 317, 319, 364, &c., 418, 421–8, Ex. 24 to Chap. IX. and 10 to Chap. XI.

V.—*On the Heat Developed in the Combination of Acids and Bases.* Second Memoir. By THOMAS ANDREWS, M.D., F.R.S., Hon. F.R.S.E., Vice-President of Queen's College, Belfast.

(Read 6th June 1870.)

In a paper communicated to the Royal Irish Academy in 1841, I gave an account of a large number of experiments on the heat disengaged when acids and bases, taken in the state of dilute solution, enter into combination, and when bases, insoluble in water, are dissolved in dilute acids. The following general conclusions or laws were deduced from those experiments :—

Law 1.—The heat developed in the union of acids and bases is determined by the base and not by the acid, the same base producing, when combined with an equivalent of different acids, nearly the same quantity of heat; but different bases, different quantities.

Law 2.—When a neutral is converted into an acid salt, by combining with one or more atoms of acid, no change of temperature occurs.

Law 3.—When a neutral is converted into a basic salt, by combining with an additional proportion of base, the combination is accompanied with the evolution of heat.*

Three years later I laid before the Royal Society of London the results of an experimental investigation of the heat developed when one base is substituted for another in chemical compounds. The law deduced from this inquiry is implicitly involved in the foregoing, of which it may indeed be regarded as a necessary consequence. It was enunciated in the following terms :—

Law 4.—When one base displaces another from any of its neutral combinations, the heat evolved or abstracted is always the same, whatever the acid element may be, provided the bases are the same.†

Finally, the law of metallic substitutions, first announced in the "Philosophical Magazine" for August 1844, was thus stated in a paper published in the "Philosophical Transactions" for 1848.

Law 5.—When an equivalent of one and the same metal replaces another in a solution of any of its salts of the same order, the heat developed is always the same; but a change in either of the metals produces a different development of heat.

In 1845 a paper appeared by GRAHAM on the heat disengaged in combinations, the second part of which refers to the heat produced when hydrate of

* Transactions of the Royal Irish Academy, vol. xix. p. 228.

† Philosophical Transactions for 1844, p. 21.

potash is neutralised by different acids.* The results arrived at by this distinguished chemist exhibit a close agreement with those contained in my first communication to the Royal Irish Academy.

The concluding part of the elaborate memoir of MM. FAVRE and SILBERMANN on the heat disengaged in chemical actions is chiefly devoted to the same subject. A large number of experiments are described, which are nearly a repetition of those I had previously published. Their results bear a general resemblance to those given by myself in 1841; but they widely differ in the details. The authors of this able memoir fully recognise the accuracy of my fourth law, which asserts the equality of thermal effect when one base is substituted for another. "M. ANDREWS," they observe, "avait en effet établi que, quelque soit l'acide d'un sel, la quantité de chaleur dégagée par la substitution d'une base à une autre pour former un nouveau sel est la même, lorsque l'on considère les deux mêmes bases."†

In a preceding paragraph of the same memoir, the authors object to what they conceive to be my first law, and state that it is not in accordance with the results of their investigations. As the question is one of some importance, I may perhaps be permitted to quote the passage in the original language. "Ses conclusions, savoir: que la chaleur dégagée par l'équivalent d'une même base combinée aux divers acides est la même, ne s'accordent pas avec les résultats de nos recherches, et ne nous paraissent pas pouvoir être admises." No doubt, through inadvertence, MM. FAVRE and SILBERMANN have here given an inaccurate statement of my first law. It did not declare that precisely the same amount of heat is disengaged by all the acids in combining with the same base, but that the heat is determined by the base, "the same base producing, when combined with an equivalent of different acids, *nearly* the same quantity of heat." A comparison of the results of MM. FAVRE and SILBERMANN with those in my original memoir will show that I had fully recognised and described the deviations from the other acids, exhibited, on the one hand, in excess, by the sulphuric acid, and on the other, in deficiency, by the tartaric, citric, and succinic acids. "If we refer," I remarked, in the original memoir of 1841, "to the first, second, and fourth tables, as being the most extensive, from the large number of soluble compounds formed by potash, soda, and ammonia, it will be observed that the sulphuric acid developes from 0°·8 to nearly 1° more than the mean heat given by the other acids; while the tartaric, citric, and succinic acids fall from 0°·4 to 0°·55 short of the same. A minute investigation of the influence of the disturbing sources of heat will no doubt discover the causes of these discrepancies. The high numbers for sulphuric

* Memoirs of the Chemical Society, vol. ii. p. 51.

† Annales de Chimie et de Physique 3ème serie xxxvii. p. 497 (1853).

acid are probably connected with that acid's well known property of developing much heat when combining with successive atoms of water. All the other acids develope nearly the same amount of heat in combining with the same base, the greatest divergences from the mean quantity being, in the case of potash, + 0°·24, and − 0°·13; in that of soda, + 0°·26, and − 0°·14; and in that of ammonia, + 0°·17 and − 0°·05. These differences are almost within the limits of the errors of experiment."*

But although there is a superficial agreement between my original results and those of MM. Favre and Silbermann, they will be found, when examined closely, to differ widely in detail, and on points of great importance. I had found that the oxalic acid disengages almost exactly the same amount of heat in combining with the soluble bases as the hydrochloric, nitric, and many other mineral acids, and this observation I have always regarded as one of the main foundations of Law 1. MM. Favre and Silbermann, on the contrary, have inferred from their experiments that "the following organic acids—the oxalic, formic, valeric, and citric—disengage sensibly the same quantity of heat, but it is less (plus faible) than that given by the foregoing mineral acids"—among which they enumerate the nitric and hydrochloric. According to my experiments, no distinction of this kind can be admitted between acids derived from the mineral and organic kingdom, inasmuch as the oxalic acid developes at least as much heat in combining with the bases as the hydrochloric, nitric, and several other strong mineral acids.

The experiments to be described in this paper were made some years ago, but their publication has been deferred from accidental circumstances. I have, however, recently repeated a few of the more important of them, with a slightly modified form of apparatus. The solutions were taken in so dilute a state that the heat disengaged never exceeded 3°·5 C. A standard solution of sulphuric acid was prepared and carefully analysed, by precipitating a given weight with a soluble salt of barium, and weighing the sulphate of barium. The strength of the alkaline solutions was adjusted with great care by means of this standard acid. The same solution of each alkali was employed in all the experiments, and the quantity used in each experiment was determined by careful weighing. The acid solution was of such a strength that, after being mixed with the alkali, an excess of two or three per cent. of acid was present. The alkaline solution was contained in a light glass vessel, in which a large platinum crucible holding the acid was carefully floated. By giving a rapid rotation, by means of a light stirrer, to the acid solution in the platinum crucible, a perfect equilibrium of temperature was soon established between the two liquids. The initial temperature of the solutions was usually about 1°·5 below that of the air, and the final temperature of the mixture about 1°·5 above it. The corrections for the

* Transactions of the Royal Irish Academy, vol. xix. p. 240.

heating and cooling action of the surrounding medium were determined with great care. The mechanical process of adding the acid to the alkaline solution produced no change of temperature, and as the heat disengaged in the combination raised the liquid almost instantly to the maximum temperature, the whole correction required was for cooling. The first temperature was read one minute after the addition of the acid to the alkaline solution, the mixture being stirred during the whole of that time. If δ represents the correction, and ϵ the excess of temperature above the air in centigrade degrees, the value of δ will be given by the following expression :—

$$\delta = \epsilon \times 0^{\circ}{\cdot}012 .$$

As a proof of the accuracy of the method of mixture adopted in this inquiry, I may mention that, being desirous to know whether the dilute acids employed in these experiments produced any change of temperature when mixed with water, I made the experiment with nitric acid by the method just described, substituting water for the alkaline solution, with the unexpected result of a fall of $0^{\circ}{\cdot}01$. On varying the conditions of the observation, so as to obtain a larger effect, it was ascertained not only that a diminution of temperature had actually occurred, but that the observed fall represented approximately its true amount. When hydrochloric acid of equivalent strength was diluted to the same extent, an elevation of temperature of $0^{\circ}{\cdot}05$ was produced.

The accuracy of experiments of this kind, where the whole thermal effect observed amounts only to 2° or 3°, depends greatly on the thermometer employed. Unless its indications are perfectly trustworthy in every part of the scale, the labour of the inquirer will only end in disappointment. I have therefore taken every precaution to secure this important object. The tube of the thermometer was calibrated and divided with care, according to an arbitrary scale, by means of a dividing instrument contrived for the purpose, and provided with a short screw of great accuracy made by Troughton & Simms. The divisions, etched finely on the glass, corresponded to about $0^{\circ}{\cdot}05$ C., and the readings could be made with certainty to less than $0^{\circ}{\cdot}01$. The division of the scale, corresponding to 0°, was determined from time to time in the usual way ; and another point, about 30° C., was fixed by comparison with four other thermometers similarly constructed, whose scales extended from the freezing to the boiling point of water. The readings of these four instruments, when reduced to degrees, rarely differed from each other within the limits to which they could be read, or $0^{\circ}{\cdot}02$. The reservoir of the thermometer used in these experiments was 75 millimetres long, and, when immersed in the liquid, occupied nearly its entire depth.

As some uncertainty always exists with regard to the thermal equivalent of glass vessels, I made two sets of comparative experiments—one with a thickly varnished copper vessel, and the other with a vessel of platinum. The mean

result of these experiments coincided almost exactly with the result obtained when the glass vessel was employed.

The weight of the glass vessel which contained the alkaline solution was 58 grammes, and corresponded thermally to 11·4 grammes of the solutions formed. The thermal equivalent of the reservoir of the thermometer and of the stirrer was 0·9 grammes. The alkaline solution weighed 160 grammes, and contained the equivalent of 1·738 grammes of SO_3. The acid solution weighed 42·5 grammes. Hence the entire thermal value of the apparatus, in terms of the solution formed, was—

Solution, ...	202·5
Glass vessel, ...	11·4
Thermometer and stirrer, ...	0·9
	214·8 grammes.

A correction (additive) of $\frac{1}{240}$ was made to the direct readings for the mercury in the stem of thermometer. The results are given to thousandths of a degree, but this apparent minuteness is due to the reduction of the indications of the arbitrary scale to degrees.

In the following detailed statement of the experimental results, Inc. is the increment of temperature observed, corrected for the mercury in stem, and δ is the correction for cooling.

Potash and Sulphuric Acid.

Inc.	3°·358	3°·356	3°·366
δ	·010	·024	·021
	3°·368	3°·380	3°·387

Mean increment corrected, 3°·378

Potash and Nitric Acid.

Inc.	2°·971	2°·976	2°·977
δ	·018	·019	·017
	2°·989	2°·995	2°·994

Mean increment corrected, 2°·993

Potash and Hydrochloric Acid.

Inc.	3°·004	3°·002	3°·005
δ	·017	·019	·017
	3°·021	3°·021	3°·022

Mean increment corrected, 3°·021

Potash and Oxalic Acid.

Inc.	3°·036	3°·048	3°·040
δ	·017	·017	·016
	3°·053	3°·065	3°·056

Mean increment corrected, 3°·058

Potash and Acetic Acid.

Inc.	2°·835	2°·846
δ	·016	·007
	2°·851	2°·853

Mean increment corrected, 2°·852

Potash and Tartaric Acid.

Inc.	2°·707	2°·717	2°·730
δ	·014	·014	·013
	2°·721	2°·731	2°·743

Mean increment corrected, 2°·732

Soda and Sulphuric Acid.

Inc.	3°·322	3°·335
δ	·025	·024
	3°·347	3°·359

Mean increment corrected, 3°·353

Soda and Nitric Acid.

Inc.	2°·914	2°·919
δ	·012	·012
	2°·926	2°·931

Mean increment corrected, 2°·929

Soda and Hydrochloric Acid.

Inc.	2°·963
δ	·019
	2°·982

Increment corrected, 2°·982

Soda and Oxalic Acid.

Inc.	3°·029	3°·013
δ	·019	·020
	3°·048	3°·033

Mean increment corrected, 3°·040

Soda and Acetic Acid.

Inc.	2°·816	2°·812
δ	·017	·018
	2°·833	2°·830

Mean increment corrected, 2°·831

Soda and Tartaric Acid.

Inc.	2°·693	2°·693
δ	·019	·015
	2°·712	2°·708

Mean increment corrected, 2°·710

Ammonia and Sulphuric Acid.

Inc.	2°·967	2°·959
δ	·017	·010
	2°·984	2°·969

Mean increment corrected, 2°·976

Ammonia and Nitric Acid.

Inc.	2°·556	2°·551
δ	·010	·015
	2°·566	2°·566

Mean increment corrected, 2°·566

Ammonia and Hydrochloric Acid.

Inc.	2°·609	2°·607
δ	·015	·015
	2°·624	2°·622

Mean increment corrected, 2°·623

Ammonia and Oxalic Acid.

Inc.	2°·635	2°·630
δ	·015	·016
	2°·650	2°·646

Mean increment corrected, 2°·648

Ammonia and Acetic Acid.

Inc.	2°·469	2°·482
δ	·017	·016
	2°·486	2°·498

Mean increment corrected, 2°·492

Ammonia and Tartaric Acid.

Inc.	2°·365	2°·354
δ	·017	·016
	2°·382	2°·370

Mean increment corrected, 2°·376

In the following table I have collected the foregoing results, arranging the acids in the order of their thermal action.

Acid.	Potash.	Soda.	Ammonia.
Sulphuric Acid, . .	3°·378	3°·353	2°·976
Oxalic Acid, . . .	3°·058	3°·040	2°·648
Hydrochloric Acid, . .	3°·021	2°·982	2°·623
Nitric Acid, . . .	2°·993	2°·929	2°·566
Acetic Acid, . . .	2°·852	2°·832	2°·492
Tartaric Acid, . . .	2°·732	2°·710	2°·376

It is interesting to observe how closely the results in the three vertical columns agree relatively with one another. The acids follow in the same order under each base, and even the differences in the amount of heat disengaged by the several acids in combining with the different bases approximate in many cases closely to one another. Thus the heat given out when the sulphuric acid combines with potash exceeds that given out when the oxalic acid combines with the same base by 0°·320, the corresponding differences in the case of soda and ammonia being 0°·313 and 0°·328. If, in like manner, we compare the differences between the heat disengaged by the acetic and tartaric acids, we fall upon the numbers 0°·120, 0°·122, and 0°·116. Even in the case of the oxalic, hydrochloric, and nitric acids, which disengage so nearly the same amount of heat, the same order is observed with the three bases. It must be particularly remarked that the oxalic acid disengages from 0°·022 to 0°·058 more heat in combining with these bases than the hydrochloric acid, and from 0°·065 to 0°·111 more than the nitric acid. The conclusion of MM. Favre and Silbermann, that the organic acids (oxalic, formic, acetic, &c.) disengage sensibly less heat than the mineral acids, is thus entirely disproved; and the original results recorded in my work of 1841, according to which the oxalic acid disengages at least as much heat as the nitric, phosphoric, arsenic, hydrochloric, hydriodic, boracic, and other mineral acids (with the exception of the sulphuric acid) are fully confirmed. The tartaric, citric, and succinic acids, it is true (as was also shown in the same work), give out about $\frac{1}{14}$th less heat than the average of the other acids; but the acetic and formic acids fall scarcely $\frac{1}{30}$th below the mean, and the oxalic acid is always above it. These results, in all their main features, are fully corroborated by the experiments recorded in this paper, which were performed with a more perfect apparatus and a more exact thermometer than I had at my command in my earlier investigations. A reference to the same paper will show that, while acids, differing so widely from one another as the oxalic, phosphoric, arsenic, nitric, hydrochloric, and boracic acids, scarcely present any sensible difference in the quantities of heat which they disengage in combining with the bases; and while of the other acids examined the sulphuric acid (and probably also the sulphurous acid) presents an extreme deviation of

about $\frac{1}{8}$th above the mean, and the tartaric acid group a deviation of about $\frac{1}{30}$th below it; the bases, on the contrary (and the subsequent researches of FAVRE and SILBERMANN have confirmed this result), differ altogether in thermal power from one another. Thus equivalents of the oxides of magnesium and of silver give out 4°·1 and 1°·8 of heat respectively in combining with nitric acid, the former oxide having therefore 2·3 times the thermal power of the latter. Yet, as is well known, both these bases fully saturate the acid, and the resulting solutions are even neutral to test paper. For these reasons, I have no doubt whatever that the first law, as enunciated in 1841, is the expression of a true physical law, and that in the combination of acids and bases in presence of water the heat disengaged is determined by the base and not by the acid. It is true that in this, as in similar physical inquiries, experimental results cannot immediately be obtained free from complication or disturbing influences. The same remark applies to the experimental proof of the great law discovered by DULONG and PETIT, which connects the specific heats and atomic weights of the elementary bodies, and also to that of the remarkable relations discovered by KOPP between the composition and boiling points of many organic liquids. We have already seen an illustration of one of these disturbing influences, in the fact that dilute nitric acid, when mixed with water, gives a slight fall of temperature, hydrochloric acid, a rise; and the differences of specific heat in the solutions formed will to a small extent modify the results. But the cause of the higher thermal power of sulphuric acid I have not been able to discover, and future researches must decide whether it depends upon some disturbing cause, or (which is less probable) upon its possessing an exceptionally high thermal power. One condition is, however, essential, or Law 1 will not apply. The acid and base must be capable of combining when brought into contact, and of forming a stable compound. In the paper so often referred to, I showed that hydrocyanic acid and potash, which fail to fulfil this condition, do not disengage the normal amount of heat when mixed; and the same observation will doubtless be found to apply to a large number of metallic oxides, which form unstable compounds with, and imperfectly neutralise, the bases.

As regards the experimental proofs of the other laws, even those of the fourth law, the truth of which is admitted by MM. FAVRE and SILBERMANN, they are only approximative; and here also we meet occasionally with peculiar and unexpected results. Thus a slight fall of temperature occurs, as HESS showed long ago, in the conversion of the neutral sulphate of potash into the acid salt; and I found, as indeed might have been expected from their alkaline reaction, that in the conversion of the ordinary phosphates and arseniates into super salts, a disengagement of heat occurs, amounting to about one-seventh of that disengaged in the formation of the salts themselves. In other cases results, at first view startling and apparently anomalous, will be found to be strictly in

accordance with the general principles already laid down. In the formation of double salts there is no disengagement of heat—a principle announced in 1841, and which ought perhaps to be enunciated as a distinct law, although it is implicitly involved in Law 2. Again, if tribasic phosphoric acid or arsenic acid is added in fractional portions to a solution of potash till the subsalts are formed, the heat disengaged on each addition of acid corresponds to the amount of acid added; but after this point has been reached, the disengagement of heat follows a different law. The pyrophosphoric acid, on the other hand, behaves in the same way as the nitric and most other acids, when added in successive portions to solutions of potash or soda; equal increments of heat being evolved for equal additions of acid, till the pyrophosphate of potash or soda is formed.*

APPENDIX.

In the following tables I have given the results described in this communication and those of 1841 in a form which admits of comparison with one another, and with those of MM. Favre and Silbermann. I have also added a few determinations recently made by M. Thomsen of Copenhagen.† It will be seen that the original experiments of 1841 exhibit, on the whole, a fair agreement with those now communicated to the Society. From the small scale on which they were performed (the whole weight of the solutions after mixture being less than 30 grammes), the imperfect form of the apparatus, and the uncertainty of the thermometric indications, I have indeed been surprised to find them so near the truth. The results of MM. Favre and Silbermann do not exhibit the precision which might have been expected from the high character of those experimentalists, and from the accuracy of other parts of their great work. The mercurial calorimeter employed by them appears to have been little adapted to its purpose; but after making due allowance for its imperfections, I am at a loss to account for the serious errors into which they have fallen. M. Thomsen's experiments have evidently been made with care, and his results agree comparatively with my own; but the absolute amount of heat obtained by him falls far short of what I have found. It is indeed much easier to obtain results relatively than absolutely correct. The numbers given in this paper will, I believe, be found rarely to differ *relatively* more than $\frac{1}{200}$th from the truth, but they may hereafter require a small correction in respect to their *absolute* value. That correction can, however, be scarcely more than $\frac{1}{50}$th of the whole amount; and I have little doubt that the number, for example,

* Transactions of the Royal Irish Academy, vol. xix. pp. 245–248. The observations of Graham confirm the statement that no heat is evolved in the formation of any double salt. Memoirs of the Chemical Society, vol. i. p. 83.

† Poggendorff's Annalen, cxxxviii. p. 78.

given by THOMSEN to express the heat disengaged in the combination of soda with nitric acid will prove to be as far below the true number as that given by MM. FAVRE and SILBERMANN is above it.

TABLE I.—*Potash.*

Acid.	ANDREWS, 1841.	FAVRE and SILBERMANN.	ANDREWS, 1870.
Sulphuric, . . .	16330	16083	16701
Nitric, . . .	15076	15510	14800
Hydrochloric, . .	14634	15656	14940
Oxalic, . . .	14771	14156	15124
Acetic, . . .	14257	13973	13805
Tartaric, . . .	13612	13425	13508

TABLE II.—*Soda.*

Acid.	ANDREWS, 1841.	FAVRE and SILBERMANN.	ANDREWS, 1870.	THOMSEN.
Sulphuric, .	16483	15810	16580	15689
Nitric, . .	14288	15283	14480	13617
Hydrochloric, .	14926	15128	14744	13740
Oxalic, . .	14796	13752	15032	...
Acetic, . .	14046	13600	14000	...
Tartaric, . .	13135	13651	13400	...

TABLE III.—*Ammonia.*

Acid.	ANDREWS, 1841.	FAVRE and SILBERMANN.	ANDREWS, 1870.
Sulphuric, ...	14135	14690	14710
Nitric, . . .	12440	13676	12683
Hydrochloric, . .	12440	13536	12964
Oxalic, . . .	12684	...	13088
Acetic, . . .	12195	12649	12316
Tartaric, ...	11400	...	11744

VI.—*The Genetic Succession of Zooids in the Hydroida.* By Professor Allman.

(Read 16th May 1870.)

Though most of the terms employed in the following paper have already become part of the language of science, some definitions may be here given with the view of rendering the subject more intelligible.

The *Zooids* are the more or less individualised members of which the hydroid colony is composed.

The *Hydranth* is the proper nutritive zooid.

The *Blastostyle* is a columnar zooid destined not for nutrition, but for the origination of sexual buds.

The *Blastocheme* is a medusiform zooid which gives origin to generative elements, not immediately, but through the intervention of special sexual buds.

The *Gonophore* is the ultimate generative zooid, that which *immediately* produces the generative elements. It may be either medusiform or sacciform.

The *Trophosome* is the entire assemblage of nutritive zooids in a colony.

The *Gonosome* is the entire assemblage of generative zooids in a colony.

From all the facts which the study of the *Hydroida* has made apparent, we may regard it as certain that however long zooidal multiplication may continue, this is not sufficient for the perpetuation of the species, but that a period must at last come in the life of the hydroid when by an act of true sexual reproduction, new individuals are produced for the indefinite extension of the species through time.

This truth finds its expression in Steenstrup's famous law of "Alternation of Generations,"—a law which, though not very correctly enunciated by its framer, may be regarded when properly expounded as a statement of the fact, that in certain animals every act of embryonal development is followed by one or more acts of zooidal development, which invariably conduct us to an ovum in which embryonal development followed by zooidal development again occurs, and the entire series becomes thus repeated.

Now the various series expressing this alternation of sexual with non-sexual development, exhibit among the *Hydroida* different degrees of complication, which will be more easily understood if we attempt to present them in the somewhat technical shape of formulæ.

Let t be the trophosome, and g the gonosome, then

$$\text{I.}\quad \underbrace{t+g} \times \underbrace{t+g} \times \underbrace{t+g} \times \ldots\ldots\ldots\text{\&c.},$$

will be the general expression for the genetic succession in the life of the hydroid, the sign + indicating succession by zooidal development, and × by embryonal.

It is very seldom, however, that the trophosome consists of only a single zooid. Such rare instances are presented by *corymorpha* (fig. 1), and by certain allied forms, whose trophosomes never become developed into a colony of mutually dependent hydranths, and I believe it better to regard the hydrorhizal fibres here as elsewhere in the light of mere extensions of the hydrorhizal or fixed end of the colony, rather than in that of proper zooids—a view supported by their mode of development in the primordial hydranth. In almost every other case, the hydranths composing the trophosome become greatly multiplied by budding.

Still less tendency is there in the gonosome to present an absolutely simple condition. Indeed, the gonosome is perhaps never limited in its normal state to a single zooid, and we frequently find hundreds and even thousands of zooids entering into the composition of this portion of the hydroid colony.

But the zooids of which the colony is thus composed may not only be numerous, but may also vary in form. Those indeed which constitute the trophosome are always of a different form from those of the gonosome. In the trophosome it is rare to find any other form of zooid than that of the proper hydranth. In *Hydractinia*, however, there is associated with the ordinary hydranths the peculiarly modified ones, whose spiral form confers upon the trophosome of this genus one of its most striking features, while the nematophores of the *Plumularidæ* can scarcely be regarded otherwise than as special zooids whose morphological differentiation from the other zooids of the colony is carried to a maximum.

In the gonosome, on the other hand, the usual condition is that of variety of form among its component zooids; and it is quite common to find in one and the same gonosome, three different kinds of zooids, each with its special form among the associated zooids, and its special duty in the generative functions of the hydroid.

While the type of *heteromorphism*, or variety of form, among the zooids is fixed for every species, the *polymerism*, or simple multiplication of the component zooids, is indefinite, and varies with the age, perfection of nutrition, &c., of the individual.

If we specialise the general expression already given (I.), so as to make it

directly applicable to particular cases of heteromorphic succession in the life of the hydroid, we shall obtain the following formulæ, where *h* is used for the hydranth, *bls* for blastostyle, *blch* for blastocheme, and *gph* for gonophore—

II. Binary. $\underbrace{h + gph}_{} \times \underbrace{h + gph}_{} \times$ .....&c., *Corymorpha.* (fig. 1.)

III. Ternary. $\underbrace{h + bls + gph}_{} \times \underbrace{h + bls + gph}_{} \times$ .....&c., *Dicoryne.* (fig. 2.)

IV. Quaternary. $\underbrace{h + bls + blch + gph}_{} \times \underbrace{h + bls + blch + gph}_{} \times$ ...&c., *Campanularia.* (fig. 3.)

These formulæ present three types of heteromorphism. In II. the heteromorphism is *binary*, in III. *ternary*, in IV. *quaternary*.

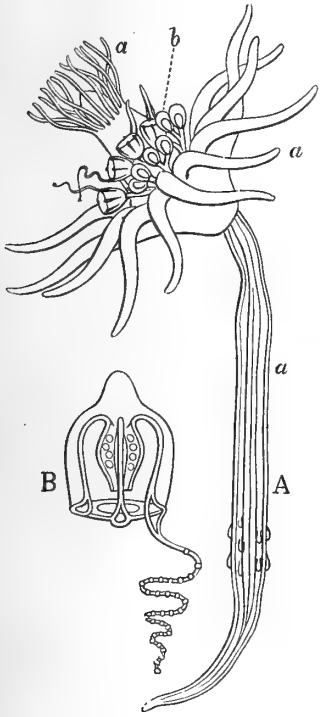


Fig. 1.—Diagram of *Corymorpha*. A, the entire colony composed of trophosome and gonosome; *aaa*, the trophosome, consisting of a solitary zooid; *b*, the gonosome, consisting of numerous zooids. B, a single zooid (gonophore) of the trophosome become free and mature.

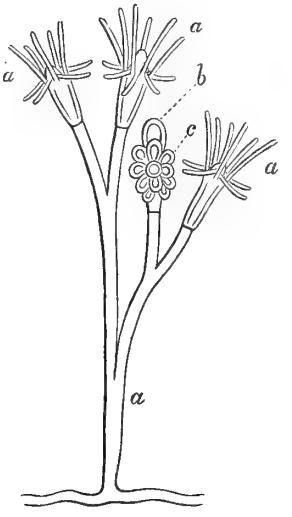


Fig. 2.—Diagram of *Dicoryne*. *aaaa*, the trophosome, consisting of numerous zooids; *bc*, the gonosome, consisting of blastostyle, *b*, and gonophores, *c*.

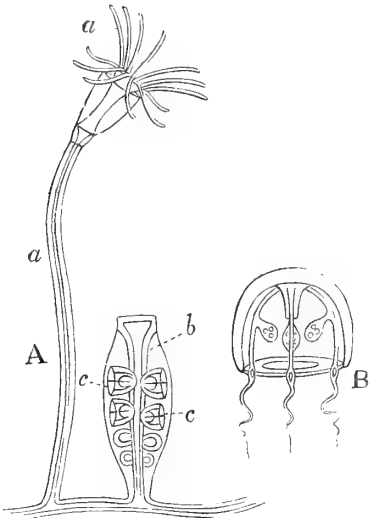


Fig. 3.—Diagram of *Campanularia*. A, portion of the entire colony; *aa*, the trophosome; *bc*, the gonosome; *b*, blastostyle; *cc*, blastochemes. B, a blastocheme become free and mature, and carrying within its bell special zooids, which are the ultimate sexual buds or gonophores.

But the hydranth may and does in almost every instance—either directly or through the medium of the common basis or hydrophyton—repeat itself

indefinitely by budding (fig. 2) before the time arrives when an element of the gonosome is to be budded off; and a series of homomorphic zooids may thus introduce themselves into the heteromorphic succession, as expressed in the following formulæ—

$$\text{V.}\quad \underbrace{h+h+h+\ldots\ldots\&c.+bls+gph}\times\underbrace{h+h+h+\ldots\ldots\&c.+bls+gph}\times\ldots\ldots\&c.$$

where the hydranth becomes indefinitely repeated in the formula of ternary heteromorphism (III.) given above; and the same will apply to each of the other two types of heteromorphism.

Now, in all these cases, the succession from the primordial nutritive zooid to the ultimate generative zooid, or gonophore, admits of being expressed in a continuous line; but one or more of the zooids of the trophosome may emit buds which will diverge from the direct line of succession, and which may then either form the starting-point for another similar line of succession, or may be destitute of all power of continuing the succession of the zooids. Thus, (figs. 4 and 7) the primordial hydranth, or any of those derived from it, may repeat itself by a bud which will diverge from the direct line, produce other zooids by gemmation, and thus start off a new series, as expressed in the following formula:—

$$\text{VI.}\quad \underbrace{h\left\{\begin{array}{l}+h+h+h+\ldots\ldots\&c.+bls+gph\\+h+h+h+\ldots\ldots\&c.+bls+gph\end{array}\right\}}\times h\left\{\ldots\right\}\times\ldots\&c.$$

And this state of things may also repeat itself indefinitely, giving rise to an indefinite number of collateral series diverging from one another, and from the primary axis of succession.

As already said, however, the diverging zooid may have no power of continuing the succession. Thus, the spiral hydranth of *Hydractinia* is not intercalated in the direct succession of zooids. It is a diverging zooid, like that which starts off the collateral series in formula VI., but one which here never gives rise to buds, and is therefore incapable of either continuing or originating a new succession.*

The following formula, where h' is the spiral hydranth, will express the place and power of this zooid in Hydractinia:—

$$\text{VII.}\quad \underbrace{h\left\{\begin{array}{l}+bls+gph\\+h'\end{array}\right.}\times\underbrace{h\left\{\begin{array}{l}+bls+gph\\+h'\end{array}\right.}\times\ldots\ldots\ldots\&c.$$

The case expressed in the formulæ given above is the simple one, where only the last hydranth in the succession of buds composing a period is supposed to

* The bifurcation occasionally observed in the spiral hydranth of *Hydractinia* is evidently abnormal, and cannot be regarded as invalidating the above statement.

give origin to a bud of the gonosome. But any other hydranth in the succession may just as well bud off a member of the gonosome, which may thus form a collateral gonosomal axis. This, indeed, is by far the most usual case, and is what is actually represented in the diagrams (see figs. 2, 4, 7). The axis, however, thus produced will be necessarily definite, and will contrast in this respect with the indefinitely extended axis of the trophosome, while it will differ from the diverging bud, h' in formula VII., by the fact of its having the power of repeating the colony by sexual reproduction, while h' has no power of reproduction, either sexual or non-sexual.

This condition may be expressed by the following formula, in which not only the last hydranth of the period gives off a bud of the gonosome, but the primordial hydranth emits a collateral gonosomal axis :—

$$\text{VIII.} \quad h \underbrace{\left\{ \begin{array}{l} + h + h + h + \ldots\ldots \&c. + bls + gph \\ + bls + gph \end{array} \right\}} \times h \left\{ \right\} \times \ldots\ldots \&c.$$

Besides the particular cases now given, certain other modifications of the plan of gemmation will at once occur to any one who has made the *Hydroida* a subject of study. Those here adduced, however, will serve to convey an adequate idea of the essential features in hydroid gemmation.

It is thus, by the combination of heteromorphic and homomorphic multiplication, and of direct and diverging series indefinitely repeated, that the animal attains to the condition of those wonderful complex colonies which impress themselves so strongly on the mind of the observer.

So also the gonosome may present not only a heteromorphic but a homomorphic multiplication of zooids. In no case, however, so far as I am aware, does any zooid of the gonosome repeat itself by homomorphic gemmation, except in some comparatively rare instances of budding in the medusa ; for though the homomorphic repetition of zooids may be in the gonosome as in the trophosome, carried to a great extent, it is almost always the result of budding from a zooid of a different form. Thus the blastostyle never emits buds destined to repeat its own form, and this form, however frequently repeated in the gonosome, is always budded off from the hydranthal element in the trophosome, its own buds, however numerous, being always heteromorphic with itself.

In the formulæ now given, one fact is obvious, namely, that the groups included between every two acts of embryonal development are exactly similar to one another in the nature and succession of their heteromorphic elements; in other words, that the life series of the hydroid may be represented by definite groups of zooids exactly repeated after each generative act.* We are indebted to Huxley for having assigned to our conception of the biological individual its

* The mere *number* of zooids in two or more of these groups may of course vary, depending as this does on the accident of abundant or deficient nutrition and the like.

proper limits, when he defined it as "the total result of the development of a single ovum," and compared the definite groups of zooids which constitute the life series of animals presenting the phenomenon of "alternation of generations" to the single organisms known as the *individuals*, which make up the *species* in other animals. These groups form the periods of the series; the period repeats itself by true generation, and this repetition continues itself indefinitely, like a circulating decimal, so as to represent the indefinitely extended life of the *species*, while the life of the *individual*—in its technical sense as the component of the species—is expressed by each period singly.

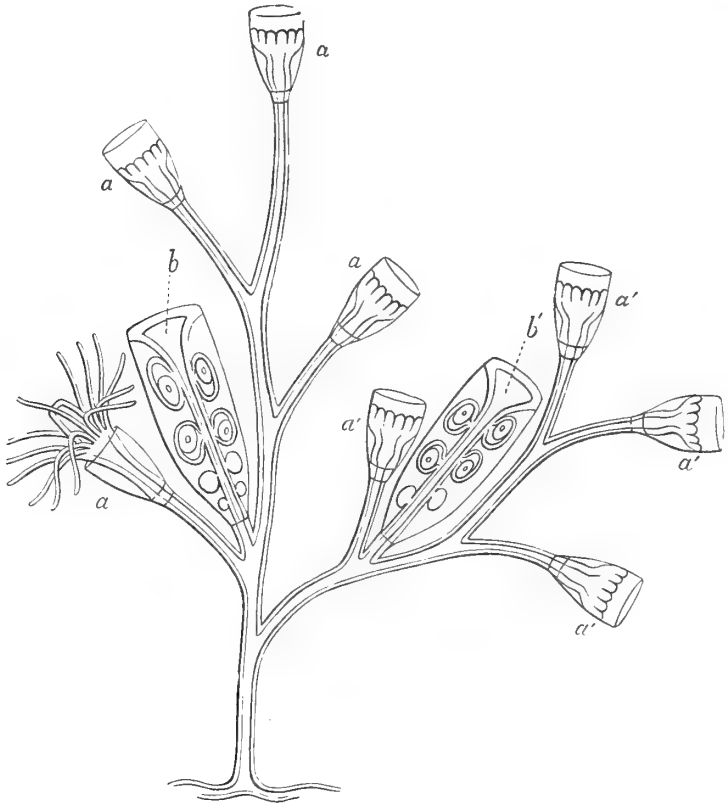


Fig. 4.—Diagram of *Laomedea*.

a a a a, hydranths belonging to the primary or direct line of succession; *a'a'a'a'*, hydranths belonging to a secondary or diverging line of succession; *b*, blastostyle of the primary line of succession, bearing gonophores, and surrounded by a gonangium; *b'*, blastostyle with gonophores and gonangium of the diverging line.

It is a universal law in the succession of zooids, that no retrogression ever takes place in the series. In other words, no bud ever becomes developed into a zooid which is of a different form from the budder, and has at the same time preceded it in the line of succesion. Thus, true hydranths are never emitted either by blastostyle, blastocheme, or gonophore; and to this law the peculiar gemminate hydriform bodies which are found on the summit of the female blastostyle in certain species of *Halecium* form no exception; for though closely resembling true hydranths, they appear to have a different signification, con-

tributing probably in some way as yet unknown to the generative functions of the hydroid, while they have no power of continuing the succession in a direct or collateral line like the proper hydranths of the trophosome.

The hydranth normally continues the axis in the hydroid colony, just as the leaf-bud in the plant continues the vegetable axis; the gonophore, on the other hand, has no power of continuing the axis, and constitutes the terminal zooid in each period of the series, just as the flower-bud stops the elongation of the axis in the plant. This analogy, however, must not be pushed too far, for while the hydranths and gonophores are simple zooids, the leaf-buds and flower-buds are complex associations of the corresponding element of individuality in the plant.

The normal order of succession of the buds in the trophosome is from the proximal or fixed to the distal or free end of the hydrosoma, so that the older buds are met with towards the base or hydrorhizal end of the main stem and branches, the younger ones towards the summit. In the gonosome, on the other hand, the order of succession is sometimes towards the distal, sometimes towards the proximal end of the axis. In the calyptoblastic genera, represented by campanularian, sertularian, and allied forms, the order of succession of the sporosacs or blastochemes is invariably from the distal towards the proximal extremity of the blastostyle on which in these genera they are always borne. When a blastostyle is present in the gymnoblastic or tubularian genera, the gonophores succeed one another, sometimes from the proximal towards the distal end (*Hydractinia echinata*), sometimes from the distal towards the proximal (*Dicoryne conferta*). In *Tubularia* their succession is from the distal towards the proximal end of the common peduncle, which is more or less developed in the various species of this genus; and the same order of succession occurs in *Corymorpha*.

Where no special gonosomal axis is developed, the succession is usually from the proximal to the distal extremity of the branch (*Bougainvillia, Perigonimus*), thus corresponding to that of the zooids of the trophosome. Sometimes, however (*Syncoryne, Gemmaria*), it is from the distal to the proximal.

We have thus, then, in the gonosome of the *Hydroida*, as in the inflorescence of plants, both a centripetal and a centrifugal order of development. It is possible, however, that irregularities may occur, and that a new bud may be abnormally emitted at the distal side of a centrifugal series, or at the proximal side of a centripetal one, so as to disturb in individual cases the normal sequence of the zooids.

Some further points admitting of comparison with the inflorescence of plants may be noticed in the gonosome of such hydroids as possess a special gonosomal axis. In *Tubularia indivisa* (fig. 5), and in the male colonies of *Tubularia larynx*, the gonophores are—like the flowers of a raceme—carried on short

pedicels along the sides of a long common peduncle, which springs from the body of the hydranth. Their order of development, however, is centrifugal, or

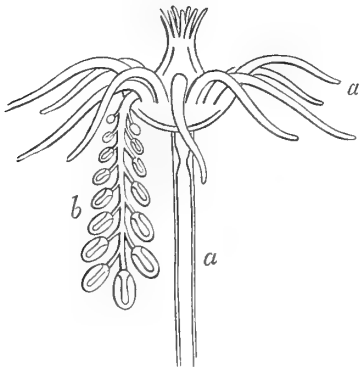


Fig. 5.—Diagram of *Tubularia indivisa*.
a a, hydranth on its stalk ; *b*, shortly stalked gonophores borne on a common peduncle, and increasing in maturity from the proximal to the distal extremity of the peduncle.

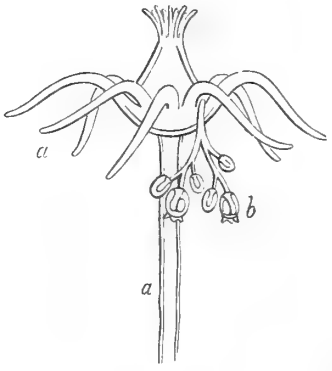


Fig. 6.—Diagram of *Tubularia larynx* (Female).
a a, a hydranth on its stalk ; *b*, gonophores attached by short stalks to a common branched peduncle, and increasing in maturity from the proximal to the distal extremities of the branches.

from the distal to the proximal extremity of the peduncle, so that the whole group may be compared to a reversed raceme. In the female colonies of *Tubularia larynx* (fig. 6), and in *Corymorpha nutans*, the pedicels become branched

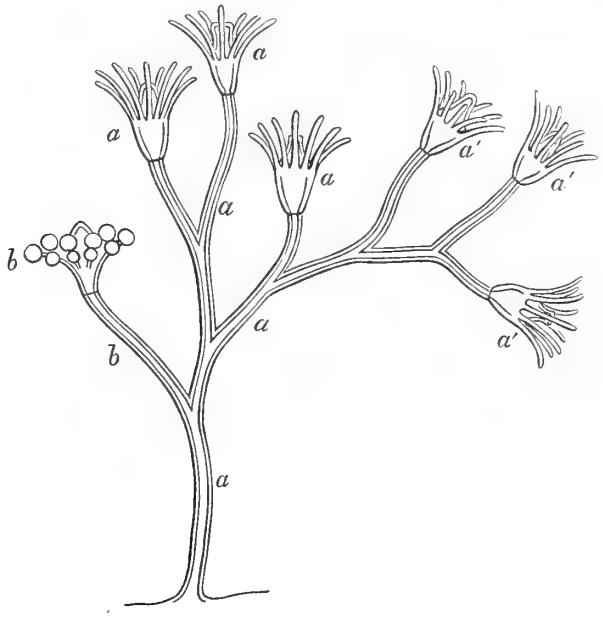


Fig. 7.—Diagram of *Eudendrium*.
a a a a a, hydranthal zooids of the direct line of succession ; *a'a'a'*, hydranthal zooids of a diverging line ; *b b*, suppressed hydranthal zooid, bearing gonophores, which are disposed in an unbelliform group.

with a similar order of development, which thus gives us the compound reversed raceme or cyme.

In certain proliferous medusæ, the buds are borne on the manubrum with

a centripetal order of development, thus giving us, according as the buds are sessile or pedunculated, the true spike, or the true raceme.

The reversed spike, or spike with a centrifugal development, shows itself in such forms as *Dicoryne conferta* (fig. 2, *b c*); while in *Campanularia* (fig. 3), *Laomedea* (fig. 4, *b b'*), *Obelia*, and other calyptoblastic forms, we have a reversed spike surrounded by the gonangial sheath; and were it not for the centrifugal development of the generative buds upon the blastostyle, and the complete closure of the gonangium, strongly recalling the spadix with its spathe in the inflorescence of an araceous plant.

In *Eudendrium* the male gonophores are disposed in an umbel (fig. 7, *b*) with the axis, in some cases prolonged beyond it, while in others there is little or no extension of the axis beyond the depressed portion which carries the gonophores. Though we cannot here recognise any difference in the order of development among the gonophores composing the umbel, we are justified in assuming this order to be as in the true umbel—a centripetal one; for in the female colonies of most species of this genus, such as *Eudendrium ramosum*,

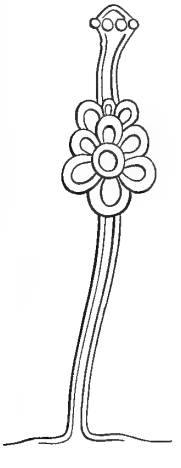


Fig. 8.
A blastostyle of *Hydractinia*, carrying its gonophores, which increase in maturity toward s tl e proximal or attached end.

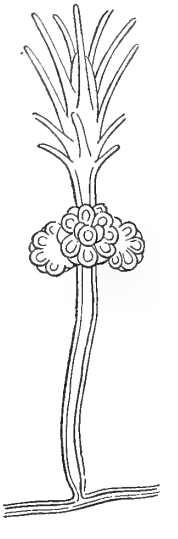


Fig. 9.
A hydranth of *Clava* with its gonophores surrounding it in globular clusters.

the gonophores are separated from distance to distance upon the stem immediately below the hydranth; and here their order of development is plainly seen to be centripetal.

In *Hydractinia echinata* (fig. 8) we have the closely approximated gonophores sessile on a blastostyle, and the development centripetal, as in the true spike, while the axis extends beyond it as a naked prolongation, reminding us of the naked prolongation of the spadix in certain *Araceæ*.

In *Clava squamata*, and in *Clava multicornis*, the gonophores form dense

clusters, surrounding the hydranth in a sort of verticil (fig. 9). Each cluster consists of sessile gonophores, borne on a greatly depressed common peduncle, and thus recalling the form of inflorescence known as a capitulum. The order of development, however, appears to be centrifugal, instead of being, as in the true capitulum, centripetal, and would therefore, perhaps, more truly suggest a comparison with the depressed cyme which constitutes the axillary inflorescence in many *Labiatæ*.

In the comparison just instituted between the gonsome of the *Hydroida* and the inflorescence of plants, it will be noticed, that whenever in the *Hydroida* the generative buds are borne upon a special gonsomal axis, like the flowers in an inflorescence, the order of succession is far more frequently a centrifugal than a centripetal one. In the calyptoblastic forms, indeed, it is always centrifugal. This is exactly the opposite of what prevails in plants; for here the centripetal forms of inflorescence greatly exceed the centrifugal ones.

We must be careful, however, not to assign to the resemblances which may be noticed more importance than they are justly entitled to. But yet, after setting aside such as are merely superficial and accidental, many still remain which have their origin in certain deep-seated properties, and may be referred to the common phenomenon of gemmation, which by agamic multiplication in the animal as well as in the plant, gives rise to colonies whose members in each case, mutually dependent on one another, continue to be organically associated into definitely arranged and determinate groups.

VII.—*Influence of the Vagus upon the Vascular System.*

By William Rutherford, M.D., F.R.S.E., Professor of Physiology, King's College, London.

(Received, April 1869. Read, 3d May 1869.)*

The innervation of the vascular system is a subject which has engrossed the attention of physiologists ever since the days of Galen. Yet, notwithstanding the number of distinguished observers who have contributed to our knowledge of this difficult topic, there are still many points of the greatest importance which are enveloped in the deepest obscurity, and not a few regarding which opinions are much at variance.

During the past three years I have been more or less engaged in prosecuting an inquiry, the chief object of which, at the outset, was to ascertain as precisely as possible the influence which the pneumogastric nerve exerts over the heart. But, as the investigation proceeded, various ideas started forth which led me to inquire into the influence which the vagus exerts over certain vascular territories, more especially the blood-vessels of the stomach. This line of research, although intricate and difficult to pursue, has nevertheless led to important results, and has enabled me to throw some light upon the manner in which the tissues rule over the blood-vessels which minister to their nutrition.

I need not, however, further anticipate here what is fully expounded in the following pages; but, before proceeding further, I desire to express my deep obligations to many of my pupils for the valuable assistance which they afforded me in the performance of the experiments. My thanks are especially due to Mr Haining, Mr Adam, Mr Alleyne, Mr Hamilton, and Mr Spence, without whose skilful co-operation my kymographic experiments must have lacked much of the precision which they happily possess.

Innervation of the Heart.

That the heart possesses within itself the conditions necessary for its rhythmical movement is a theory which was advanced by Galen, and is now believed by all physiologists.

The peculiar nervous arrangements essential for the rhythmical movement are—as Remak points out—ganglia situated in various parts of the organ.

* An Abstract of this paper was printed in the Proceedings of the above date. Urgent duties prevented me from preparing the paper in an extended form for the Transactions of 1869. By the permission of the Council its publication has therefore been delayed for a year.

It has long been known that the movements of the heart may be influenced by nerves connecting it with the cerebro-spinal axis. It is unnecessary, however, that I should enter into a full historical account of this subject, inasmuch as this has already been given at great length by Von Bezold.* I need, therefore, only say that it is now perfectly ascertained that the nerves which convey influences between the cerebro-spinal axis and heart are branches of the sympathetic and vagus. The sympathetic filaments take origin in the brain and medulla oblongata, pass through the cervical portion of the spinal cord, the last cervical and first dorsal sympathetic ganglia, and from thence to the heart (M. and E. Cyon).† These nerves convey to the cardiac organ influences which accelerate its action. Von Bezold‡ thought he had proved that they are continually prompting the heart to move; he having observed that on dividing the cervical portion of the spinal cord—wherein these nerves are contained—that the heart beats more slowly than it does previous to the injury. He, however, omitted to take into account the fact, that on dividing the cervical portion of the spinal cord nearly all the blood-vessels of the body are paralysed, and that the lowered blood-pressure which results therefrom may be the cause of the slower action of the heart which follows the lesion. The brothers Cyon found, that although retardation of the pulse follows division of the spinal cord, no such change is usually observed if the cardiac motor nerves coming from the last cervical and first dorsal ganglia are divided, although these same nerves are cut across when the cervical portion of the spinal cord is divided. We have, therefore, no reason whatever for supposing that these nerves are continually in action, but, on the contrary, the evidence advanced by the brothers Cyon is entirely opposed to such an idea.

It has also been maintained by Von Bezold§ and others, that cardiac motor nerves are to be found in the trunk of the cervical sympathetic nerve. With regard to this matter, I have performed many experiments on rabbits, and have invariably failed to observe any excitement of the heart follow stimulation of this nerve unless the irritant (electricity) was transmitted through the nerve close to the inferior cervical ganglion. In that case accelerated cardiac action often followed the irritation; but such result is no proof that the trunk of the cervical sympathetic contains motor nerves for the heart, seeing that the irritant was applied to the nerve near enough to the inferior cervical ganglion to throw into action the cardiac motor nerves derived from the spinal cord. I therefore agree with Ludwig and Weinmann,‖ in considering the cervical sympathetic as not at all a cardiac nerve.

* Von Bezold, Untersuchungen über die Innervation des Herzens, 1te und 2te Abtheilung. Leipsic, 1863.

† M. and E. Cyon, Reichert and Du Bois Reymond's Archivs, 1867, p. 389.

‡ *Lib. cit.* 2te Abtheilung, pp. 230 and 257.

§ *Lib. cit.* 1te Abtheilung, p. 147.

‖ Ludwig's Lehrbuch der Physiologie, iiter Band, p. 178.

The heart is connected with the vagus by a superior and an inferior branch. The former, in the rabbit, leaves the vagus with the superior laryngeal nerve, or it may be somewhat below the origin of the latter; it courses down the back in close proximity to the sympathetic, joins one or two branches of the inferior cervical ganglion with which it proceeds to the heart. In dogs this nerve is bound up with the trunk of the vagus and cervical sympathetic in one common trunk; in cats it is joined to the sympathetic. The function of this nerve was discovered by LUDWIG and CYON.* It is a vaso-inhibitory and also an excitocardio-inhibitory nerve; that is to say, when it acts it dilates vessels, and it also excites the filaments of the vagus (inferior cardiac branch) which inhibit the heart's movements. The influences which travel through the nerve start from the heart and pass to the medulla oblongata, there to inhibit the nerve-cells in the medulla connected with the motor nerves for the abdominal blood-vessels, and also to excite the nerve-cells in the medulla connected with the cardio-inhibitory fibres of the vagus. This nerve was named by the discoverers of its function "Nervus Depressor," because it lowers the blood-pressure; this it does by diminishing the work done by two great portions of the vascular system—the heart—and abdominal blood-vessels. The influences which travel through the nerve pass towards the medulla, probably their only starting-point is in the heart; but with the cause which determines the action of the nerve we are totally unacquainted. Its discoverers always failed to find it in action; that is to say, they never saw the blood-pressure rise when the nerve was divided. This of course was a very unsatisfactory circumstance, not a little calculated to cast grave doubts as to the real function of the nerve having been discovered at all. I am glad to say, however, that in the course of experiments hereafter to be detailed, I succeeded in finding this nerve in action on several occasions (see Experiments XLI., XLIV., XLVI., LI.) The nerve certainly acts in the manner indicated by LUDWIG and CYON; but my experiments do not enable me to state what are the causes of its being thrown into action.

The inferior cardiac branch of the vagus usually arises with the inferior laryngeal nerve, and from this origin it proceeds to the heart, where, according to BEALE,† it joins the cells of the cardiac ganglia.‡

* Sächs. Acad. Bericht, 1866, p. 307.

† Philosoph. Trans. 1863, p. 562, and fig. 41.

‡ From *physiological* evidence it is generally believed that the cardio-motor nerves (sympathetic) are also connected with the ganglia in the heart. The termination of the depressor nerves within the heart is quite unknown.

Function of the Inferior Cardiac Branch of the Vagus. *Is it motor as well as inhibitory?*

Effect of Stimulating the Nerve.

In 1845, the brothers Weber* made the well-known observation that, on irritating the vagi, or those portions of the central nervous system from which they spring, that the heart beats more slowly, and may even come to a stand-still in a state of relaxation. From this observation they concluded that the vagus exercises an inhibitory power over the heart's action. The accuracy of the experiment has ever been beyond dispute, but the explanation, though now accepted by nearly all—if not by all—physiologists, has nevertheless been opposed by such distinguished investigators as Schiff,† Moleschott,‡ and Lister.§. These authorities, while admitting that powerful stimulation of the vagus arrests cardiac action, maintained that gentle stimulation quickens it. They, therefore, concluded that the vagus is really a motor nerve of the heart, and that the arrest of cardiac action which follows powerful irritation of the nerve, is due to exhaustion of the latter.

As it is unnecessary to slay the slain, I need not adduce the arguments necessary to show how fallacious is the method of reasoning upon which these authors have hinged their conclusion,—that has already been ably done by Pflüger,‖ Von Bezold,¶ and others. I will only make a single remark, namely this,—were it true that while powerful stimulation slows the heart, weak stimulation quickens it, the conclusion that both effects must necessarily be due to the influence of the stimulant upon the same fibres of the vagus is by no means warranted. It seems to me that the only legitimate explanation which Schiff and others could have given of their facts, is that the excitement of the heart due to stimulation of the lower end of the vagus—after its section in the neck—results either from general excitement of the animal, or from the presence of cardiac motor nerves in the vagus—*in addition* to those which inhibit the heart's movements; a weaker stimulus being necessary for the former than is required for the latter.

It is settled beyond all dispute that the inferior cardiac branch of the vagus contains fibres which inhibit the heart. The experiments hitherto performed

* Omodei Annali Universali di Medicina, vol. cxvi. p. 225, November 1845.

† Experimentelle Untersuchungen über die Nerven des Herzens. Archiv. für Physiolog. Heilkunde 8ter Jahrgang.

‡ Wiener Med. Wochenschrift, 25ter Mai 1861.

§ Proc. Roy. Soc. vol. ix. p. 367.

‖ Reichert's and Du Bois Reymond's Archivs, 1859, p. 13.

¶ *Lib. cit.* Erste Abtheilung.

do not, however, seem to me to conclusively show that cardiac motor fibres are absent from this nerve. SCHIFF'S statement is that when the vagi are divided in the necks of rabbits, and the lower end of one or both nerves *very gently* stimulated, the heart's action is quickened. He has further said that it is difficult to hit upon the precise amount of stimulation which will effect this. Although other observers of undoubted reputation for skilful experimentation have failed to obtain this result, the above statement is nevertheless positive evidence which cannot be discarded unless the negative evidence be very strong. It seemed to me that it was possible to investigate this matter in a manner more exact and reliable than that adopted by previous experimenters; accordingly, I performed a number of experiments in 1866–67, in the following manner:—In frogs and rabbits I exposed the vagi in the neck, and then opened the trachea and larynx anteriorly,—in order that asphyxia and consequent excitement might be prevented, and also to enable me to see movements of the arytenoid cartilages. I then divided the vagi on a level with the thyroid cartilage. I always stimulated the nerve by induced currents obtained from DU BOIS REYMOND'S induction machine. The electrodes consisted of clean copper wire; the battery of one of DANIELL'S cells. On stimulating the lower end of the vagus, I always watched the corresponding arytenoid cartilage as well as the heart. The movement of the former served as a strict test for the proper application of the electrodes, in short—for the proper stimulation of the nerve. The observations were begun by ascertaining the strength of current necessary to affect the recurrent laryngeal filaments in the vagus—so that movement of the arytenoid cartilage ensued. Having ascertained this, I made the current still weaker, and then began the observations on the heart. As is well known, the strength of the induced currents obtained from DU BOIS REYMOND'S machine depends on the distance between the primary and secondary coils. The strength is inversely as the distance. Seeing that I began with very weak currents—that is, with the secondary far removed from the primary coil—and, being anxious to test the effect of all currents intermediate between the very weak ones at the commencement and those strong enough to retard the pulse, I always increased the strength of the current while the nerve was being stimulated, and the effect upon the heart observed. As long as the stimulus was not strong enough to slow the heart, the nerve was usually stimulated for about half a minute. Whenever the animal struggled, the observation was at once abandoned, and repeated when all excitement had subsided, —the effect of struggling being to increase the cardiac movement. In the case of rabbits, the cardiac pulsations were counted with the aid of a stethoscope, the number being taken previous to and during the stimulation of the nerve.

EXPERIMENTS ON RABBITS.

EXPERIMENT I.—8th August 1866.—Strong Rabbit. Trachea and Larynx opened. Both Vagi divided in the Neck. Du Bois Reymond's Induction Machine with one Daniell's element employed as the stimulating agent.

Time.	Distance in Millimetres of Primary from Secondary Coil of Induction Machine.	Pulse in 10″.		State of Laryngeal Muscles.
		Before Irritation of Vagus.	During Irritation of Vagus.	
			Cardiac end of left Vagus.	
4·22′	740	...	...	Contraction.
·23′	800	51	50	Rest.
·24′	800—750	52	52	„
·25′	750—730	52, 52	52, 52	Contraction.
·26′	730—700	51, 52	52	„
·27′	700—670	51	51	„
·28′	670—640	52, 52	52, 52	„
·30′	640—620	51, 52	52, 51	„
·31′	620—630	51, 50, 51	51, 50, 50	„
·33′	630—640	50, 51	51, 50	„
·38′	640—600	52, 51	50, 51	„
·40′	600—550	51, 50	51, 51	„
·41′	550—500	50, 50	51, 50	„
·44′	500—450	50	50	„
·45′	450—400	50	49	„
·48′	400—350	52, 50	50	„
·52′	350—300	50, 50	50, 48, 49	„
·54′	300—250	48, 49, 50	49, 50	„
·59′	250	50, 49	49, 49	„
5·1′	250—230	48, 50	33, 29	„
·5′	250	48, 48	48, 48	„
·8′	240	48, 49	19, 19	„

EXPERIMENT II.—Strong Young Rabbit. Trachea and Larynx opened. Both Vagi divided in the Neck. 1 Daniell.

Time.	Distance in Millimetres of Primary from Secondary Coil.	Pulse in 10″.		State of Laryngeal Muscles.
		Before Irritation of Vagus.	During Irritation of Vagus.	
			Cardiac end of right Vagus.	
10·15′	550	...	...	Contraction.
·17′	700	45	45	Rest.
·19′	700—650	44	45	„
·21′	650—600	46, 45	46, 46	„
·23′	600—550	45	45	Contraction.
·28′	550—450	46	46, 46	„
·30′	450—400	46	47	„
·32′	450—400	46, 46	46, 46	„
·34′	400—350	46	46, 45, 46	„
·36′	350—300	45	45, 44	„
·38′	300—250	44	45, 44	„

EXPERIMENT II.—*continued.*

Time.	Distance in Millimetres of Primary from Secondary Coil.	Pulse in 10″.		State of Laryngeal Muscles.
		Before Irritation of Vagus.	During Irritation of Vagus.	
10·44′	250—220	42	42	Contraction.
·46′	220—200	43, 44	44, 44	,,
·50′	200—180	42	42	,,
·52′	180—170	43	43	,,
·54′	170—160	42	42	,,
11 o'clock.	160—150	43	43	,,
· 5′	150—140	42	42	,,
· 8′	140—130	42	38	,,
·10′	130—100	42	Stoppage.	,,

EXPERIMENT III.—Strong Old Rabbit. Trachea and Larynx opened. Both Vagi divided in the Neck. 1 Daniell.

Time.	Distance in Millimetres of Primary from Secondary Coil.	Pulse in 10″.		State of Laryngeal Muscles.
		Before Irritation of Vagus.	During Irritation of Right Vagus.	
3·38′	700	48	48	Rest.
·40′	700—650	48	48	,,
·48′	630	48	48	Contraction.
·51′	630—600	48, 49	49, 48	,,
·55′	600—560	49, 48	47, 48	,,
4·2′	560—460	48	48, 49, 47	,,
·5′	460—400	48	48	,,
·6′	400—350	48	48	,,
·8′	350—300	48	48	,,
·10′	300—250	48	47	,,
·11′	250—220	47	48, 47	,,
·14′	220—200	48	40	,,
			Cardiac end of left vagus.	
4·18′	700	47	47	Rest.
·21′	700—650	47	48, 47	,,
·23′	650—600	48, 49	49, 49	,,
·25′	600—580	47	48	Contraction.
·28′	580—500	48	48, 47	,,
·30′	500—450	46, 45	45, 45	,,
·35′	450—400	45	45, 44	,,
·38′	400—350	43, 44	44, 43	,,
·42′	350—300	43	42, 43	,,
·46′	300—250	44	44, 44	,,
·49′	250—200	43	43	,,
·54′	200—185	42	36, 34	,,
·58′	150	44	26	,,
5 o'clock.	100	44	Stoppage.	,,

I might give the results of nine other experiments similar to the foregoing, but these so thoroughly agree with the above that I think it unnecessary to detail them. I shall, however, have occasion to refer to some of their results in the sequel.

EXPERIMENTS ON FROGS.

EXPERIMENT XIII.—Strong Frog. Both Vagi Divided. Larynx laid open anteriorly. Heart Exposed. Pericardium Unopened. 1 Daniell.

Time.	Distance in Millimetres of Primary from Secondary Coil.	Pulse in Half a Minute.		State of Laryngeal Muscles.
		Before Irritation of Vagus.	During Irritation of Vagus.	
			Right vagus.	
9·11′	800	16	16	Rest.
·14′	800—750	16	16, 16	,,
·17′	750—700	16	16	,,
·19′	700—650	16	16	,,
·22′	650—600	16	16	,,
·26′	600—550	16	19	Contraction.
·30′	560	16	16, 16	Rest.
·34′	550	16	15, 16	Contraction.
·37′	550—500	16, 16	16, 16	,,
·43′	500—450	16	16, 16	,,
·48′	450—400	16	16, 16	,,
·53′	400—350	15	15, 15	,,
·56′	350—300	15	16, 15	,,
·59′	300—250	15	15, 15	,,
10·4′	250—200	14	14, 13	,,
·9′	200	14	14, 12, 12	,,
·14′	200—170	14	12, 12, 10	,,
·20′	170—140	15, 14	14, 12, 11	,,
·25′	140—100	15	8, Arrest.	,,

The left vagus was then irritated, but only with a view to ascertain what was the feeblest current necessary to produce movement in the larynx, and also the weakest current which could arrest the heart's movements. A current at 530 mm. was the weakest which threw the left recurrent laryngeal nerve fibres into action, while the weakest which sufficed to arrest the heart was one at 170 mm. Further observations on the left vagus were not undertaken, seeing that the heart's action had become irregular.

EXPERIMENT XIV.—Strong Frog. Both Vagi Divided. Larnyx Opened. Heart Exposed. Pericardium Intact. 1 Daniell.

Time.	Distance in Millimetres of Primary from Secondary Coil.	Pulse in Half a Minute.		State of Laryngeal Muscles.
		Before Irritation of Vagus.	During Irritation of the Vagus.	
			Left vagus.	
4·14′	700	17	17	Rest.
·16′	700—650	17	16	,,
·19′	650—600	16	16	,,
·22′	600—580	16	16	Contraction.
·25′	580—550	16	16, 16	,,
·30′	550—500	16	16, 16	,,
·34′	500—480	16, 16	16, 16	,,
·39′	480—450	16, 16	16	,,
·44′	450—440	16, 17	17, 17	,,
·48′	440—420	17, 18	17, 16	,,
·52′	420—400	17, 17	17, 17	,,
·57′	400—380	17	16	,,
·59′	380—360	16	16	,,
5·4′	360—340	16	16, 16	,,
·8′	340—320	16, 16	16, 16	,,
·13′	320—300	16	16, 16	,,
·17′	300—280	16, 16	16, 16	,,
·21′	280—260	16	16	,,
·26′	260—250	16	16	,,
·30′	240	16	15	,,
·32′	220	16	15	,,
·35′	200	16	16	,,
·37′	180	15	16	,,
·42′	160	17	13	,,
·44′	140	17	13	,,
·48′	120	18	12	,,
·51′	100	21	Arrest.	,,

It is unnecessary for me to give the results of other two experiments upon frogs, seeing that they are precisely similar to the above. The experiments already detailed amply suffice to show the method of experimentation adopted in the inquiry. I am at a loss to conceive a mode of research better calculated to yield accurate results. The stimulation of the recurrent laryngeal fibres of the vagus served as an index of the effect of the irritant upon the very nerve supposed to contain motor fibres for the heart, and enabled me to judge whether or not the vagus was being properly stimulated. Hence the fact that I never observed quickening of the heart's action follow stimulation of the nerve although negative in its nature, is, nevertheless, I venture to think, exceedingly reliable on account of the method of procedure adopted. It may be well, however, for me to repeat, that I never registered the heart's pulsations while the animal was restless; had I done so, I might have shown that accelerated cardiac action

often follows stimulation of the vagus, but such observations must obviously have been utterly fallacious, seeing that violent movements invariably excite the heart's action. With a view to explain how SCHIFF and his supporters obtained their results, ECKHARD* has hinted that possibly the irritating current may have been sent through the vagus so low in the neck that it affected other nerves in addition to the vagus. Certainly ECKHARD's conjecture is sufficient to serve as an explanation of the above, but whether or not it be the true explanation, I cannot say, inasmuch as I did not see SCHIFF and his supporters perform their experiments.

A striking fact is very clearly brought out by the above mode of experimenting—viz., that a very much stronger irritant is necessary so to stimulate the cardio-inhibitory fibres of the vagus, that the heart's action may be retarded, than is required to stimulate the recurrent laryngeal fibres, so that the laryngeal muscles may be thrown into action. The following table demonstrates this fact :—

TABLE I.—SHOWING COMPARATIVE STRENGTH OF THE STIMULI NECESSARY TO THROW THE INFERIOR LARYNGEAL AND THE INFERIOR CARDIAC NERVES INTO ACTION.

No. of Experiment.	Nature of Animal.	Vagus Divided in Neck, Lower End Stimulated. Distance in Millimetres of Primary from Secondary Coil indicating the Weakest Current necessary.	
		(A.) To throw the Laryngeal Muscles into Action.	(B.) To Inhibit the Heart's Action.
I.	Rabbit.	740	240
II.	„	550	130
III.	„	630 Right Vagus.	210
Do.	„	590 Left „	190
IV.	„	600	240
V.	„	575	220
VI.	„	650	250
VII.	„	520	170
VIII.	„	610	260
IX.	„	660	200
X.	„	630	210
XI.	„	580	185
XII.	„	620	200
XIII.	Frog.	550	200
XIV.	„	580	160
XV.	„	620	200
XVI.	„	550	200

It may be seen, from the above table, that the strength of current necessary to stimulate the inferior laryngeal and inferior cardiac filaments in the trunk of the vagus, differed in different cases. The cause of this is probably threefold: 1*st*, The strength of the electrical current was not absolutely constant; 2*d*, The

* Experimental Physiologie des Nervensystems, 1867, p. 201.

degree of sensibility varies in different animals; 3*d*, The preparation of the nerve cannot, of course, be conducted so that precisely the same amount of injury is inflicted upon it in different cases. When I first elicited the difference between the results given in column A. and those in column B., it occurred to me that possibly the inferior laryngeal nerve fibres are more excitable than those of other motor nerves. But a few experiments on rabbits and frogs satisfied me that such is not the case. It is to the last degree unlikely that the inferior laryngeal nerve is more excitable than the inferior cardiac nerve, and, therefore, I think, we must look to the peripheral terminations of the two nerves for the explanation of the facts above given. An ordinary motor nerve may be supposed to encounter little—if any—opposition when it acts upon the muscular plasm, but the inhibitory nerve has to act on a nervous apparatus in which there are counter-influences constantly at work. Only a powerful inhibitory influence can hold these in check, and indeed so powerful are these promptings to motion within the heart, that stimulation, however strong, of the inhibitory nerve, cannot keep the heart quite still for more than a few seconds.

Having, in the above manner,* entirely failed to find any acceleration of the heart follow stimulation of the vagus, another method of experimentation suggested itself to my mind. It has been shown by Botkin that atropia paralyses the cardio-inhibitory fibres of the vagus, that is to say, it so affects them or their terminations in the heart, that when they are stimulated the frequency of the pulse is no longer diminished.† I determined to produce this paralysis, and then see whether or not acceleration of the heart's action followed irritation of the lower end of the vagus.

Experiment XVII.—In a rabbit I divided both vagi in the neck, and stimulated the lower end of the right vagus by a powerful current (Secondary 40 mm. distant from primary coil of induction machine. One Daniell). The heart's action was arrested. I then injected ten milligrammes of atropia sulphate into the jugular vein. When two minutes had elapsed, I stimulated the same nerve with a current of the same strength. The heart's action, instead of being arrested as before, was slightly accelerated. Before stimulation of the nerve, the pulse in 20″ numbered 90—during stimulation it numbered 96. After an interval of four minutes, I stimulated the nerve again with the same current. Before stimulation the pulse was 104 in 20″—during stimulation it rose to 112. After a further lapse of time, I excited the lower end of the left vagus in the same manner, but no acceleration of the pulse ensued. The acceleration of

* Should the reader at any time have occasion to repeat the above experiments, he will require to observe the arytenoid cartilages very narrowly, in order to detect the finest movements which may result from irritation of the vagus. The animal should be arranged so that the light may be reflected from the inner surface of the arytenoid cartilage. The slightest movement of the glittering mucous surface can then be readily detected.

† Virchow's Archivs, Band xxiv., 1862, p. 89.

the pulse in this case took place when no signs of excitement were exhibited by the animal, it therefore seemed to indicate that the right vagus, at any rate, contains efferent cardio-motor nerves* which are not paralysed by atropia sulphate. The following experiment led me to abandon this idea :—

Experiment XVIII.—In a rabbit I divided the trunk of the left vagus in the neck, dissected down upon the subclavian artery, and divided the inferior cardiac branch of the right vagus. I then severed the trunk of the vagus on the right side of the neck and irritated its lower end with an induced current (secondary coil 80 mm. from primary coil. One Daniell). The *heart's action was accelerated.* Before stimulation the heart gives 92 beats in 20″—during stimulation the number rose to 100. On repetition of the above a similar result was obtained. The acceleration in this case could not possibly be due to the action of any motor nerves contained in the inferior cardiac branch of the vagus, for that branch had been divided on the same side as that on which the trunk of the vagus was irritated. I, therefore, concluded that in this and in the preceding experiment, the acceleration of the heart's action was probably due to a reflex excitement of the heart resulting from spasm of the laryngeal and œsophageal muscles, as well as the greatly increased movement of the stomach and intestines which follows powerful stimulation of the lower end of the vagus.

I have, therefore, entirely failed to find any evidence to the effect that the inferior cardiac branch of the vagus contains any cardio-motor fibres in addition to those which are cardio-inhibitory in their action.

Effect upon the Vascular System of Section of the Vagi in the Neck.

It is well known that division of both vagi in the cervical region is—in the case of mammals at any rate—usually followed by accelerated cardiac action and increase of the arterial blood-pressure.

(a.) *Cause of the accelerated Cardiac Action.*

Reid† ascribed it to "the struggles and terror of the animal produced by division of the nerves." Undoubtedly this is to some extent true, but acceleration of the heart may be observed after division of the vagi during complete narcotism produced by opium. Brown-Séquard‡ thought that the excitement of the heart is due to accumulation of carbonic acid in the blood ;—it being well known that division of the vagi is usually followed by a slower rate of respira-

* Since the above was read I have experimented still further with regard to this point. The experiments which I have performed on rabbits and cats have convinced me thoroughly that the vagus does not contain "accelerator" fibres for the heart, and that any acceleration of the heart which may be observed when the lower end of the vagus is stimulated after atropia-poisoning is not due to a direct action of the vagus upon the heart.

† Physiological Researches, 1848, p. 132.

‡ Jl. de la Physiologie, v. p. 656.

tion. Considering that this distinguished physiologist long ago pointed out the irritating effects upon certain nervous centres, which result from accumulation of this substance in the blood, it is not surprising that he should have advanced the above theory. The following experiment shows, however, that acceleration of the pulse may follow section of the vagi although a hyperoxygenated condition of the blood be maintained before and after the section.

Experiment XIX.—In a strong rabbit I exposed the vagi, introduced a canula into the trachea, and then by means of a special apparatus maintained artificial respiration with such rapidity, that the respiration could be completely stopped for twenty seconds without slowing of the heart ensuing. It was, therefore, certain that a hyperoxygenated state of the blood had been fairly produced.* While care was taken to maintain the artificial respiration at the same rate, I divided the vagi and watched the results for some time after. They arethe following :—

Time.		Pulse in 15″.		
5·12′	Previous to Hyperoxygenation	60	61	59
„ 16′	„ division of Vagi	59	60	58
„ 17′ 14″	Vagi divided			
„ 22′		65	64	64
„ 26′		66	64	65

The above facts show that a quickened action of the pulse may follow section of the vagi although the slightest approach to asphyxia is prevented. Further, recent researches by Voit and Rauber† prove, that until the pulmonary textures undergo inflammation the increased depth of the respirations after division of the vagi entirely compensates for their diminished frequency, so that the amount of oxygen and carbonic acid in the blood undergoes no change.

It is now generally believed that the acceleration of the pulse after division of the vagi is due to escape of the heart from the restraining influence of these nerves, and seeing that the acceleration very frequently follows the above-mentioned lesion, it is inferred therefrom that the cardio-inhibitory fibres of the vagi are in almost constant action. It occurred to me that if this explanation be the true one, and the only one, we should expect to find no acceleration of the heart follow division of the vagi after their cardio-inhibitory fibres have been paralysed by such a substance as atropia. Accordingly, I performed a number of experiments with a view to test this point; but as these bear equally upon the following question, I shall briefly allude to it before proceeding further.

* Usually within three seconds after the respiration of a rabbit is arrested the heart comes almost to a stand-still. This is due to irritation of cardio-inhibitory nerves by the asphyxiated condition of the blood.

† Centralblatt. 1868. No. 47.

(b.) *Cause of the Increased Blood-Pressure.*

During the operation of the cardio-inhibitory nerves, the work done by the heart is diminished (see fig. 2). The rise in the blood pressure, which commonly follows section of the vagi, is therefore ascribed by all to increased force and frequency of the heart's contractions. If this be the only cause of the rise in the blood-pressure, then we ought to find that it undergoes no exaltation on division of the vagi during a paralysed state of their cardio-inhibitory fibres.

The following experiments were undertaken with a view to furnish an answer to this question. Do accelerated cardiac action and increased blood-pressure follow division of the vagi—during paralysis of their cardio-inhibitory fibres—produced by such a substance as atropia sulphate?—

EXPERIMENTS SHOWING THE EFFECT UPON THE BLOOD-PRESSURE AND FREQUENCY OF THE PULSE WHICH SOMETIMES FOLLOWS SECTION OF THE VAGI IN ANIMALS WHERE THE CARDIO-INHIBITORY NERVES ARE PARALYSED BY SULPHATE OF ATROPIA.

EXPERIMENT XX.—A SMALL TERRIER DOG. CANULA IN CAROTID ARTERY. TRACHEA OPEN.

Time.	Pulse in 15″.	Mean Pressure in inches of Hg.*	General Notes.
11·44′	16	4·5	
47′	16	4·5	
30″			0·67 milligramme atropia sulphate injected into vein.
48′ 30″	40	4·65	
50′ 30″	29	4·2	
52′	22	4·4	
30″			0·4 milligramme atropia sulphate injected into vein.
53′	35	4·2	
54′	29	4	
55′ 30″	25	3·9	
56′			Right vagus divided in the neck.
57′ 30″	23	4	
58′ 30″			Left vagus divided in the neck.
59′	56	5·9	
45″	50	5·9	
12· 2′	42	6·4	
8′	43	6·45	
30″			Distal end of left vagus irritated by a strong induced current, but no effect was produced on the heart's action, clearly showing that the cardio-inhibitory nerves were completely paralysed.

* In all these experiments LUDWIG's Mercurial Kymograph was used.

In the above, notwithstanding the paralysis of the inhibitory nerves of the heart, section of the vagi was followed by a most distinct increase in the frequency of the heart's contractions, and a rise in the blood-pressure.

EXPERIMENT XXI.—A Middle-sized Collie Dog. Canula in Carotid Artery. Trachea open.

Time.	Pulse in 15″.	Mean Pressure in inches of Hg.	General Notes.
12· 3′	29	5·9	
9′			0·67 milligramme atropia sulphate injected into vein.
10′	35	5·6	
30″	35	5·3	
11′			0·4 milligramme atrophia sulphate injected into vein.
12′	36	5·2	
13′	33	5·6	
15′	32	5·3	
30″			Left vagus divided.
17′	35	5·8	
20′ 30″			Right vagus divided.
22′	39	6·6	
23′	39	6·8	
28′	40	6·8	
29′			Cardio-inhibitory nerves proved to be paralysed.

EXPERIMENT XXII.—A Spaniel Dog, five months old. Canula in Carotid Artery. Trachea open.

Time.	Pulse in 15″.	Mean Pressure in inches of Hg.	General Notes.
11·19′	27	3·6	
20′ 30″	26	4·6	
23′	26	4·05	
30″			0·67 milligramme atropia sulphate injected into vein.
24′	30	4·05	
27′	38	4·05	
30″			0·4 milligramme atropia sulphate injected into vein.
28′ 30″	66	4·3	
30′	60	4·1	
31′ 30″	60	3·9	
35′	50	3·9	
40′	53	4·1	
41′			Left vagus divided.
42′	60	4·3	
30″			Right vagus divided.
45′	68	5·1	
47′			The cardio-inhibitory nerves were found to be completely paralysed.

EXPERIMENT XXIII.—Old Spaniel Dog. Canula in Carotid Artery. Trachea open.

Time.	Pulse in 15″.	Mean Pressure in inches of Hg.	General Notes.
4.28′	25	5·1	
30″			2 milligrammes atropiæ sulph. injected into vein.
29′	46	7·1	
34′			Clot in canula. Apparatus cleaned.
42′	42	4·9	
43′	38	4·3	Hitherto the respiration has been rapid and irregular.
48′	40	4·7	Animal sobbing.
49′			20 minims Tincturæ Opii given.
30″	40	6·1	
52′			Clot in canula. Apparatus cleaned.
54′	33	4·6	
55′			0·13 milligramme atropiæ sulph. given.
56′ 30″	34	4·6	
59′			Left vagus divided.
5 o'clock.			Clot. Apparatus cleaned.
3′ 30″	— ?	4·9	
4′			Right vagus divided.
5′ 30″	41	5·1	
6′ 30″	40	5·61	
9′	43	5·2	
12′	44	5·4	
13′			Cardio-inhibitory nerves found to be completely paralysed.

These experiments show that in dogs division of the vagi in the neck may be followed by accelerated cardiac action and increased blood-pressure, although the cardio-inhibitory nerves be paralysed. It is clear, therefore, that physiologists generally are mistaken in supposing that the acceleration of the pulse which commonly follows division of the vagi, is entirely due to the heart's being liberated from its controlling nerves. A portion—perhaps, in some cases, the whole—of that acceleration may be due to division of other filaments than those which retard the heart's action. I shall not, at present, enter into a discussion of the causes of the increased blood-pressure observed in these experiments. The reason for this will be readily perceived when my remarks upon other experiments performed on dogs have been perused. (See page 137.)

The consideration of these changes which follow division of the vagi will be resumed after we have inquired into the present state of our knowledge regarding the

Innervation of Blood-Vessels.

By the investigations of Bernard and Brown-Séquard, it has been estab-

lished that the contractile elements of the blood-vessels are supplied by motor nerve filaments derived from the sympathetic. Diminution in the calibre of the blood-vessels is produced by these nerves. According to LUDWIG and THIRY, the general centre for the vasomotor nerves is situated in the medulla oblongata. This cerebro-spinal centre is more or less constantly in action, whereby vessels are usually kept in a semi-contracted state. The amount of contraction in the vessels—in other words, the degree of activity of the cells in the vasomotor centre—may be increased or diminished by certain nerves which convey influences to the medulla. BERNARD* was the first to show, by experiment, that vessels may be dilated by the irritation of certain nerves. He found that when he divided the auricular nerves in rabbits, and excited their central ends, the vessels of the ear of the same side became turgid. Slight contraction preceded the dilatation. LOVÉN† has confirmed BERNARD'S observation, and has shown that dilatation of vessels in the rabbit's leg follows irritation of its afferent nerves; in short, that dilatation of the vessels of a part may be produced by influences transmitted through the afferent nerves of that part to the cerebro-spinal vasomotor centre. Like BERNARD, he found that transient contraction generally precedes the dilatation of the vessels so induced. The most remarkable instance of a nerve capable of dilating vessels is to be found in the superior cardiac branch of the vagus already alluded to. When this nerve is divided and its cranial end stimulated, dilatation of abdominal blood-vessels takes place without any previous contraction, such as commonly results when a mixed nerve such as the sciatic or the trunk of the vagus is stimulated. In all the above cases the vascular dilatation succeeds stimulation of the central ends of the divided nerves; that is to say, the peripheral end of the cranial portion of the divided nerve. Two facts, however, have been discovered which are opposed to the idea that the motor centre for all the blood-vessels of the body lies in the medulla oblongata; one concerns the submaxillary ganglion, the other, the ganglia upon the nervi erigentes of the penis. It is well known that if the chorda tympani nerve be divided, and its peripheral end stimulated, dilatation of the blood-vessels in the submaxillary gland is the result. In like manner, as recently shown by ECKHARD‡ and LOVÉN§, when the nervi erigentes are divided in the dog and the peripheral portions stimulated, erection of the penis results, principally from the dilatation of vessels induced by the irritation. On these nerves there are many ganglionic corpuscles; and the most feasible explanation of this vascular dilatation in the case of the submaxillary gland and penis is, that the ganglionic cells existing in connection with these structures, are in part, at any rate, vasomotor cells, and correspond to the ganglia in the heart. These three groups of ganglia

* Jl. de la Physiologie, 1862, p. 416.
† LOVÉN, Ludwig's Arbeiten, 1866, p. 1.
‡ Beiträge. Giessen, 1863.
§ *Lib. cit.* p. 18.

forming three *peripheric* motor centres connected with the vascular system, the only ones as yet known. But it is interesting to observe that the submaxillary and cardiac ganglia are obviously very directly connected with the medulla oblongata by motor and inhibitory nerves, and although nothing can be stated with precision regarding the central connections of the ganglia presiding over the vessels of the penis, they have, nevertheless, probably an intimate connection, like the others, with the medulla. The dilatation of vessels which results from the action of these vaso-inhibitory nerves is, as regards the vessel, passive; it is due to the elasticity and blood-pressure being no longer opposed by the action of the contractile elements of the vascular wall, these having been brought to rest by a cessation of action in the vasomotor nerve apparatus.

The vasomotor nerves may have their action increased as well as diminished by the action of other nerves. The contraction of vessels in distant parts by the sudden application of cold to it may be a small extent of skin. The remarkable increase in the blood-pressure which follows stimulation of the central end of the superior laryngeal nerve (Aubert and Roever),* the contraction of vessels and increase of blood-pressure which usually follows the gentle stimulation of the central ends of mixed nerves, are some of the facts which support this idea; such nerves may be very appropriately termed excito-vasomotor nerves. These nerves appear all to pass inwards to the vasomotor centre in the medulla oblongata.

Other facts might be mentioned, but I may briefly say that every advance in our knowledge of this question only tends more and more convincingly to show that the innervation of the contractile elements of the blood-vessels is similar to that of the cardiac muscular fibres. These contractile elements are directly supplied by motor nerve fibres; and the evolution of energy in the cells connected with the latter may be diminished by one set of nerve fibres—cardio and vaso-inhibitory—and increased by another—excito-cardio and excito-vasomotor.

The idea commonly prevails that when a part becomes the seat of active nutritive change, its blood-vessels undergo dilatation by reason of the increased attraction for blood manifested by the tissues. The *vis à fronté* is supposed to become so powerful that it can overcome the contraction of the arterial walls, and thereby produce dilatation. It struck me that the vascular dilatation in such a case is possibly the result of an influence transmitted by the tissue through its vaso-inhibitory nerves. The only author who has come near to this idea is Lovén. A considerable time after the above had presented itself to my mind, he published the excellent memoir† to which reference has already been made. He showed that the blood-vessels of a part may be dilated by artificial

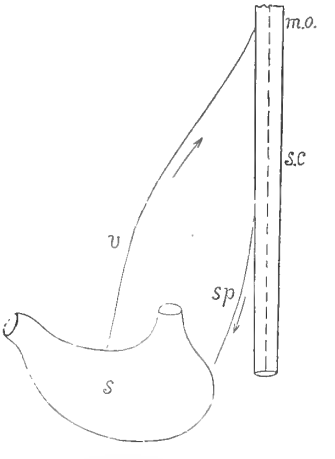
* Centralblatt, 1868, p. 578.

† *Lib. cit.*

stimulation of the afferent nerves of that part. There, however, he stopped. He has advanced no theory regarding the bearings of this fact upon our conceptions of the mode in which vascular dilatation in a part commonly takes place, nor has he thrown out any suggestion as to the agent by which these nerves are normally brought into play. I believe that the experiments which I have yet to detail will be found to very decidedly advance our knowledge regarding this matter.

The vasomotor nerves for the blood-vessels of the stomach are contained in the splanchnic nerves. The vaso-inhibitory and excito-vasomotor nerves of that organ appear to me to be for the most part, if not entirely, contained in the pneumogastric nerves. If it be true—as I imagine—that when the gastric blood-vessels undergo dilatation, vaso-inhibitory nerves are brought into play, we should—if these nerves be contained in the vagi—expect to find that if the vagi be divided during dilatation of gastric blood-vessels, the vessels will undergo contraction, and we should desire to see that stimulation of the upper end of the divided nerve is able to produce dilatation of vessels. In order that the sequel may be better understood, I would refer the reader to the following diagram representing the stomach, *s;* the vagus, *v;* the splanchnic nerve, *sp;* the medulla oblongata, *m. o.;* and the spinal chord, *s. c.* The arrow near the vagus indicates the direction in which vaso-inhibitory and vaso-excito motor influences travel through the vagus to affect the vasomotor centre in the medulla oblongata—while the arrow near the splanchnicus indicates the direction in which vasomotor influences travel through that nerve to the gastric blood-vessels.

Fig. 1.—Diagram showing innervation of Gastric Blood-vessels.



Stomach, *s.* Spinal Cord, *s.c.* Medulla Oblongata, *m.o.* Vagus, *v.* Splanchnicus, *sp.*

The following experiments were undertaken to ascertain whether or not one can obtain evidence of the passage of vaso-inhibitory influences through the vagus during the dilatation of the blood-vessels of the stomach which takes place during digestion, and also to ascertain the effect of irritating the vagus upon the gastric blood-vessels :—

Influence of the Vagi upon the Blood-vessels of the Stomach.

Effect of Division and Irritation of the Nerves.

(*a.*) *During Digestion.*

Experiment XXIV.—Rabbit two months old. Three hours after food was given the vagi were exposed, and the trachea opened in order to prevent asphyxia and consequent struggling. The abdomen was opened, and the stomach found to be largely distended with food, and its outer surface very vascular. Intestines were moderately vascular. The stomach was then opened by an incision extending from right to left along its anterior surface, and its contents partially everted. The lining membrane was of a dusky red hue. The vagi were divided in the neck four minutes after the exposure of the gastric mucous membrane. *Pallor of the membrane followed immediately upon the division of the nerves,* and remained during the time occupied by the rest of the experiment—forty-five minutes. The superior cardiac branches of the vagi (depressor nerves) were then divided; the result was a slight increase in the pallor of the mucous membrane.

The effects of irritating the vagi were now attended to. The irritant used was Faradic Electricity from Du Bois Reymond's machine, with 1 Smee's cell.

Time after Division of Vagi.	Distance of Primary from Secondary Coil of Machine in Millimetres.	Nerve Stimulated.	Result as regards redness of Gastric Mucous Membrane.
10′	230	Upper end left vagus.	No evident change.
12′	180	Upper end left vagus.	Became redder.
13′	10 milligrammes atropiæ sulph.* given to paralyse cardio-inhibitory fibres of vagus.		
15′	180	Lower end left vagus.	No evident change.
21′	120	Upper end right vagus.	Pallor followed by slight redness.
25′	80	Upper end right vagus.	Pallor.
34′	70	Lower end right vagus.	No evident change.
44′	70	Lower end left vagus.	No evident change.

Experiment XXV.—Full-grown strong rabbit fed two and a half hours before the experiment was begun. Abdomen opened; stomach and intestines very vascular. Division of the vagi was followed by decidedly diminished vascularity of the outer surface of the stomach which was in this case unopened. Owing to an interruption the experiment was not carried beyond this point.

* Although this substance paralyses the *cardio*-inhibitory, it does not paralyse the *vaso*-inhibitory nerves.

Experiment XXVI.—Strong full-grown rabbit. Fed two hours before the experiment. The cavity of the stomach was not opened. When the superior cardiac branches* of the vagi were divided, no evident change resulted in the vascularity of the stomach or intestines. On dividing the vagi *the whole outer surface of the stomach became paler;* but no such change was observed in the mesentery or intestines. The vascular change in the stomach was permanent.

The upper ends of both vagi were then repeatedly stimulated, with variable results. Sometimes the surface of the stomach became paler, at other times redder. Irritation of the lower ends of the nerves produced no effect.

Experiment XXVII.—Rabbit; fed an hour before the vagi were divided. The outer surface of the stomach was not apparently so vascular as in the three former cases. Division of the vagi produced no evident change on the gastric vessels.

Experiment XXVIII.—A cat fed on milk an hour previous to division of the vagi. On section of these nerves the vascularity of the outer surface of the stomach instantly became greatly diminished, and remained so.

(b.) Section of the Vagi during Fasting.

Experiment XXIX.—Full-grown rabbit which had fasted for twelve hours. Outer surface of stomach pale. Division of depressor nerves produced no evident change in gastric or intestinal vessels. *Division of both vagi likewise produced no evident change in gastric or intestinal vessels.* Irritation of upper end of right vagus (1 Smee, secondary 200 mm. distant from primary coil) caused slight reddening of outer surface of stomach, no change on intestinal vascularity. This observation was repeated with a stronger current (secondary coil at 150). A slight increase in the pallor of the stomach was the immediate result, but this yielded during the continuance of the irritation to distinct reddening of the gastric wall. The irritation was continued for twenty seconds. Anæsthesia was then produced by means of chloroform in order to get rid of the effects of the irritant upon the sensory nerve centres. The upper end of the right vagus was then stimulated (secondary coil at 100). Slight but distinct increase in the gastric vascularity at once ensued. Irritation of the upper end of the left nerve yielded the same result. Irritation of the lower ends of the nerves caused no change.

Experiment XXX.—Full-grown rabbit which had fasted for fourteen hours. Division of the nervi depressores and vagi produced no evident change on the vascularity of the outer wall of the stomach or of the intestines, which both before and after the division were but slightly vascular.

* These nerves produce dilatation of abdominal blood-vessels.

Time after Division of Vagi.	Distance of Primary from Secondary Coil of Induction Machine.	Nerve Stimulated.	Result as regards Gastric Vascularity.
	mm.		
7′	200	Upper end of right vagus irritated for 30″.	Slight reddening.
12′	150	Upper end of right vagus irritated for 30″.	Pallor succeeded by well-marked redness.
15′	120	Upper end of right vagus irritated for 15″.	The same result.
Chloroform was now given until complete anæsthesia resulted.			
20′	120	Upper end of right vagus irritated for 30″.	Slight increase of pallor succeeded by well-marked redness.
24′	80	Upper end of right vagus irritated for 30″.	The same result.

Experiment XXXI.—Cat which had fasted for sixteen hours. The blood-vessels of the outer surface of the stomach were small and contracted. Division of the nervi depressores and vagi produced no apparent change in the vascularity of the stomach or intestines. Irritation of the upper end of the vagus caused tolerably distinct blushing of the gastric wall.

The general result of the experiments just given is, that section of the vagi produces no change in the gastric blood-vessels if these be not in a dilated condition, such, *e.g.*, as obtains during digestion, while division of these nerves during dilatation of the gastric vessels is generally followed by marked and permanent contraction of these vessels. It is true that this result did not occur in one (experiment xxvii) of the five experiments in which the nerves were divided during digestion. In that case, however, it was quite evident that the gastric vessels were not so dilated as they usually are; but, of course, such a statement is not without fallacy, seeing that every case cannot be identical as regards the vascular dilatation that obtains during digestion. I am not, therefore, prepared to give any decided opinion regarding the results of experiment xxvii; but it seems clear that the general result of the effects of division of the vagi supports the idea that, during digestion, vaso-inhibitory influences pass in a centripetal direction through the vagi. The effects of irritating the cut ends of the nerves were various. It is certain that no evident change in the vascularity was ever produced by stimulating the lower ends of the nerves, so we may safely say that the influences which pass through the nerves to control the gastric vessels certainly do not pass in a centrifugal direction. When the upper ends of the nerves were subjected to sufficiently powerful stimulation, pallor of the gastric wall sometimes followed, at other times blushing; frequently the blushing succeeded the pallor, and sometimes no perceptible effect resulted.

These results receive a feasible explanation by the supposition that the vagus, like other mixed nerves, contain fibres which excite, and those which inhibit contraction of the vessels. Because the vagus is a mixed nerve, the results of its division must obviously be more trustworthy than the results of its stimulation. We cannot suppose that while during digestion influences pass from the stomach through the vagi to inhibit the gastric vessels, there are also influences travelling from the same source which produce an opposite effect; and, therefore, we may expect that when we divide these nerves during the dilatation of vessels which obtains during digestion, we shall simply stop the transit of those vaso-inhibitory influences from the stomach, hence the division of such nerves is a much simpler case than artificial stimulation, seeing that during such stimulation we must throw into play fibres whose functions are antagonistic.

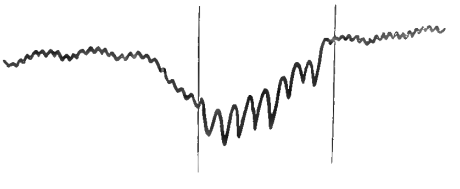
Seeing that the experiments just given show what are the evident changes in the gastric vessels that follow stimulation of the vagi, it is convenient to give here results of experiments which show the effect of this stimulation upon the arterial blood-pressure.

Effect upon the Arterial Blood-Pressure which follows Stimulation of the Vagus after its section in the Cervical Region.

(a.) *Stimulation of the Lower End of the Nerve.*

If the lower end of the vagus be stimulated by a sufficiently powerful current, the heart's action is retarded, the work done by that organ is diminished, and in consequence the arterial blood-pressure falls. The following tracing by Ludwig's Kymograph from the carotid artery of a rabbit affords a good illustration of the above fact. The tracing *must be read from right to left.* The vertical lines have been added to show when the vagus was at rest and when it was stimulated. The portion of the tracing between the two lines shows the influence of the cardio-inhibitory fibres of the vagus upon the heart.

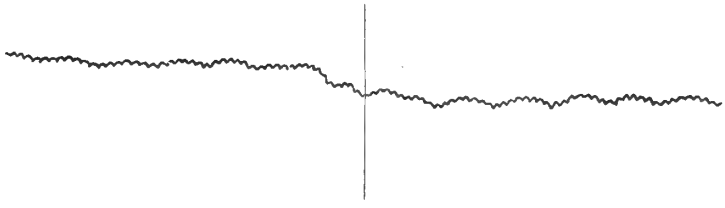
Fig. 2.



The above trace shows the influence of the vagus upon the heart, but it contains no indication as to whether or not the vagus contains vasomotor fibres. This fact can only be ascertained by stimulating the nerve after its influence over the heart has been got rid of. I accordingly paralysed the cardio-inhibitory fibres by sulphate of atropia, and then stimulated the lower end of the nerve as before. The results were various. If the animal were not paralysed

by curara, a slight rise in the blood-pressure frequently resulted from the stimulation. Such a result is shown in the following tracing from a rabbit.

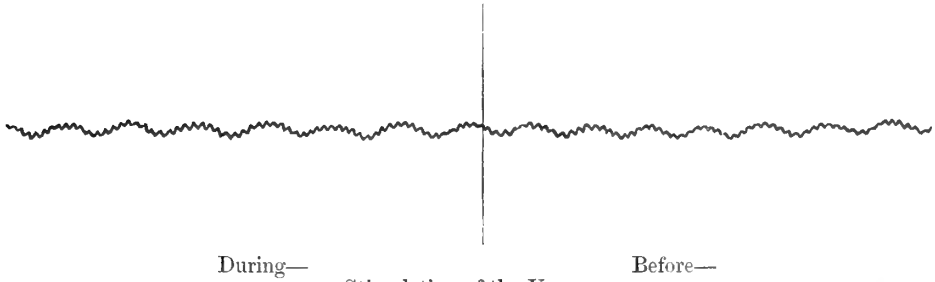
Fig. 3.



Stimulation of the Vagus.*

A change similar to the above is, however, by no means the rule even in the same animal. The following tracing shows no change in the blood-pressure during stimulation of the vagus, although it was taken shortly after the foregoing from the same animal, and although the lower end of the same vagus was stimulated by a current of the same strength.

Fig. 4.



Stimulation of the Vagus.

This tracing represents what I always found when the atropised vagus was stimulated in cases where the influence of extraneous movements upon the blood-pressure had been got rid of by means of curara paralysis. We may, therefore, say, that the vagus certainly contains no vasomotor-nerve fibres which act in a centrifugal direction, for if it did, stimulation of the nerve after palsy of its cardio-inhibitory fibres would always raise the blood-pressure whether curara be given or not.

(b.) *Stimulation of the Upper End of the Nerve.*

Already much has been written with regard to the changes in the blood-pressure which result from stimulating the upper end of the vagus after it has been cut across in the cervical region. According to DRESCHFELD† such stimu-

* In reading tracings taken by such an instrument as LUDWIG's Kymograph, it is necessary to remember that the vertical variations in the mercurial column are always the double of what the tracing indicates, because the tracing shows the movements of a column of mercury in a U-shaped tube.

† Von BEZOLD's Untersuchungen, 1867, p. 326.

lation always raises the blood-pressure, but if the cerebrum be removed, or if it be paralysed by morphia, vagus stimulation always lowers the pressure.

This is simply untrue. Stimulation of the nerve may *increase or lower* the pressure whether morphia narcotism be induced or not. Since I performed my experiments on this subject, KOWALEWSKY and ADAMUK,* AUBERT and ROEVER† have published the results of their researches regarding this question, and I am glad to say that these exactly agree with what I had previously found. Seeing that these authors have already published results similar to mine, I need not do more than briefly say, that when the upper end of the vagus is stimulated, the respiration is very apt, more especially in rabbits, to come to a stand-still. As a result of this, carbonic acid accumulates and oxygen diminishes in the blood, thereby bringing about a condition of that fluid which acts as an irritant to the vasomotor centre in the medulla, and increases the tonicity of the blood-vessels so that the blood-pressure is raised. This source of fallacy must be guarded against by using artificial respiration. Struggling, too, is apt to result from stimulation of the upper end of the vagus, to guard against which we may narcotise the animal by means of opium, or may produce paralysis by curara. When we give opium or curara and then stimulate the nerve, a rise in the blood-pressure is not so frequently observed as when the nerve is stimulated before these poisons are administered; obviously because extraneous convulsive movements have been got rid of. However, whether we give these toxic agents or not, stimulation of the upper end of the vagus in rabbits and cats (where the depressor nerve is a separate branch) may be followed by increase or by diminution of the blood-pressure, most frequently the latter. I have often observed that in the same animal a rise or fall of the blood-pressure may be obtained by using for the production of the latter a more powerful stimulus than that which may have been found sufficient to produce the former. The explanation of this seems to be, that in the case of the vessels, as in that of the heart, a weaker stimulus suffices to throw the excito-motor nerves into action than is necessary to cause the inhibitory nerves to produce their effect. The following tracings illustrate the results of stimulating the upper end of the vagus. *They must be read from left to right.*

The fibres in the vagus, then, which influence *blood-vessels*, all convey influences *towards* the medulla oblongata, and these fibres appear to be both vaso-inhibitory and excito-vasomotor, the former causing dilatation of blood-vessels and consequent lowering of the blood-pressure (fig. 5), the latter causing contraction of blood-vessels and consequent increase of the blood-pressure (fig. 6). Doubtless the influences which travel through these two kinds of

* Centralblatt, 1868, p. 546. † Ibid. p. 578.

nerve-fibres start from the parts to which the vagus is distributed, principally, therefore, from the stomach and lungs.

Fig. 5.—Fall in blood-pressure on irritating upper end of vagus in a rabbit (both vagi divided), to which 10 milligrammes of atropia sulphate had been given. (Secondary 30 mm. distant from primary coil. One Daniell.)

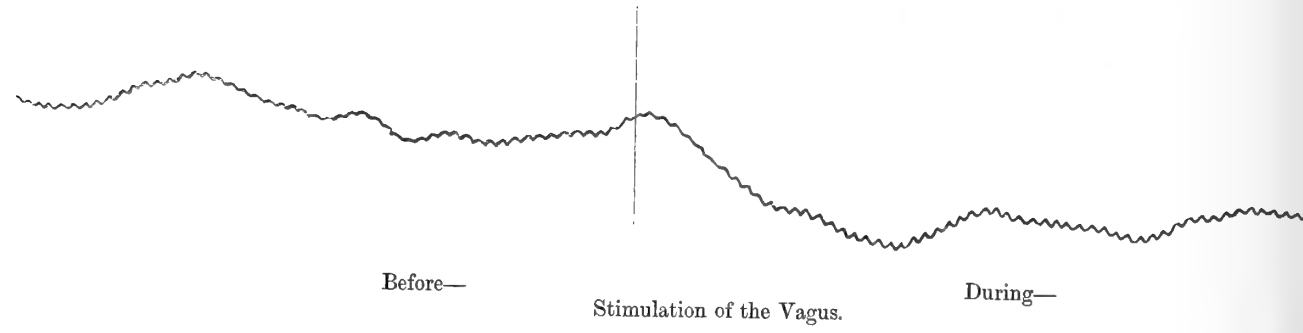
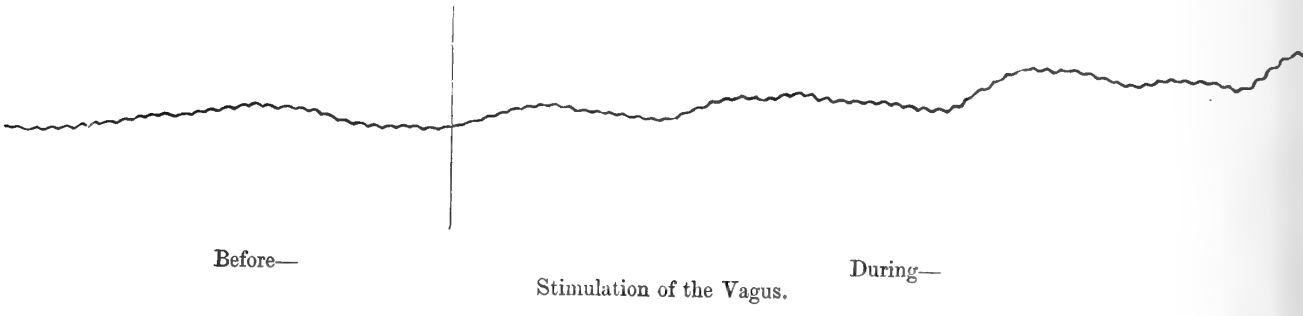


Fig. 6.—Rise in blood-pressure on irritating upper end of vagus in the same rabbit as that from which the foregoing tracing was taken. (Secondary 120 mm. distant from primary coil. One Daniell.)



Having seen what are the effects upon gastric blood-vessels of division and stimulation of the vagi, and also the changes which the latter gives rise to as regards the blood-pressure, we shall now consider the effect of *division of the nerves* as regards the blood-pressure. The experiments on each class of animals are divided into two groups: 1st, those showing the effect of dividing the nerves during digestion, and those showing the effect of this during fasting. The main object of the whole being to ascertain whether or not during the former, vaso-inhibitory influences are transmitted from the stomach through the vagi to diminish the action of the vasomotor nerves ruling over the gastric blood-vessels, and thereby to bring about dilatation of these. While this is the main point of the experiments, they at the same time furnish data which serve to explain the acceleration of the pulse which sometimes follows division of the vagi after paralysis of their cardio-inhibitory fibres (see page 122).

Experiments showing the Effect of Division of the Vagi upon the Blood-Pressure and Frequency of the Pulse in Animals during Digestion, and during Fasting.

A. EXPERIMENTS ON DOGS.

(a.) *During Digestion.*

Cardio-inhibitory Nerves paralysed by Atropia.

EXPERIMENT XXXII.—Retriever Puppy about Three Months old, fed Three hours before the experiment. Canula in Carotid Artery. Trachea open.

Time.	Pulse in 15″.	Mean Pressure in inches of Hg.	General Notes.
4·51′	34	4·5	
59′ 30″			3 milligrammes atrop. sulph. injected into vein.
5·0′ 15″	46	4·7	
5′	46	4·7	
12′			Both vagi divided.
16′	52	5·9	
21′	50	6·1	
27′	50	5·9	
33′	54	6·3	
34′			Cardio-inhibitory nerves found to be completely paralysed.

Result.—Increase of pressure and acceleration of pulse after division of vagi.

EXPERIMENT XXXIII.—A Terrier Dog, fed at 1.30 p.m. Canula in Carotid Artery. Trachea open.

Time.	Pulse in 15″.	Mean Pressure in inches of Hg.	General Notes.
3·32′ 20″	30	5.7	
50″	30	5·7	
37′			1 milligramme atrop. sulph. injected into vein.
38′ 15″	56	6·6	
40′	62	6·7	
45′	56	6·7	Vagi not paralysed.
55″	56	6·2	
50′			1 milligramme atrop. sulphate given.
20″	56	6·2	
53′ 50″			Both vagi divided.
55′	62	7·4	
35″	60	7·6	
58′ 55″	54	7	
59′ 15″			Cardio-inhibitory nerves found to be quite paralysed.

Result.—Permanent increase of pressure, and temporary acceleration of pulse after division of vagi.

EXPERIMENT XXXIV.—A Strong Retriever Dog, fed Two hours before the experiment. Canula in Carotid. Trachea open.

Time.	Pulse in 15″.	Mean Pressure in inches of Hg.	General Notes.
12·14′	32	6	
17′	32	6	
23′			2 milligrammes atrop. sulph. injected into vein.
25′	28	4·8	
27′	30	5	
31′ 30″	30	5·4	Vagi not quite paralysed.
32′			1 milligramme atrop. sulph. given.
30″	42	4·1	
35′	36	4·8	
36′	32	4·8	
38′ 30″	35	5	
43′			Both vagi divided.
50′	38	6·4	
52′	35	6·8	
1· 3′	34	6·7	
4′			Cardio-inhibitory nerves still paralysed.

Result.—Permanent increase of pressure, and temporary acceleration of pulse after division of vagi.

EXPERIMENT XXXV.—Small Dog Fed at One o'Clock. Canula in Carotid. Trachea open.

Time.	Pulse in 15″	Mean Pressure in inches of Hg.	General Notes.
5·49′	30	5	
50′			2 milligrammes atropia sulphate injected into vein.
40″	70	5·8	
53″	66	5·4	
54′ 10″	66	5	Both vagi divided.
40″			
56′	64	9·1	
59′	60	7·9	
6· 2′	56	6·4	
5′	56	6·5	
10′	53	6·6	

Result.—Increase of pressure after division of vagi. The frequency of the pulse was diminished; but it is doubtful whether or not a similar decrease would not have taken place had the vagi remained intact. When the pulse undergoes a great increase in frequency on the administration of atropia, as in the present instance, a steady decrease almost always sets in shortly afterwards.

(b.) *During Fasting.*

1. *Cardio-inhibitory Nerves Paralysed by Atropia.*

EXPERIMENT XXXVI.—A Strong Retriever Dog which had Fasted for Seventeen Hours. Canula in Femoral Artery. Trachea open. 3 Milligrammes Atropia Sulphate Injected into Vein at 10·10 a.m.

Time.	Pulse in 10″.	Mean Pressure in inches of Hg.	General Notes.
10·15′	33	6	
16′	33	6	
18′	33	6·4	
20′			Both vagi divided.
23′ 30″	34	6·4	
45″	33	6·6	
24′ 10″	33	6·3	
40″	34	6	
26′	33	6·4	
27′	32	6·3	
28′	34	6	
30″			Cardio-inhibitory nerves found to be completely paralysed.

Result.—Division of vagi, followed by no change in blood-pressure, or frequency of pulse.

EXPERIMENT XXXVII.—Terrier which had Fasted for Eighteen Hours. Canula in Carotid Artery. Trachea open.

Time.	Pulse in 15″.	Mean Pressure in inches of Hg.	General Notes.
11·46′	30	5	
51′	31	5·3	
52′			2 milligrammes atropia sulphate injected into vein.
57′	50	5·5	Both vagi divided.
58′			
59′ 39″	49	5·4	
12· 2′	48	5·5	
8′	46	5·2	Cardio-inhibitory nerves ascertained to be paralysed.
8′ 30″			

Result.—Division of vagi, followed by no change in blood-pressure or frequency of pulse.

EXPERIMENT XXXVIII.—Strong Retriever Dog which had Fasted for Seventeen Hours. Trachea open. Canula in Femoral Artery.

Time.	Pulse in 10″.	Mean Pressure in inches of Hg.	General Notes.
12·23′	28	5·3	Animal sobbing.
25′ 20″	24	5·4	Animal sobbing.
40″			3 milligrammes atropia sulphate injected into vein.
26′ 50″	28	5·4	The animal is now quiet.
49′ 20″	27	5·2	
51′ 45″			Both vagi divided.
56′ 10″	22	5·9	
58′	22	6	
1· 1′ 40″	20	5·6	
6′	22	6	
16′	22	5·9	
17′			Cardio-inhibitory nerves still paralysed.

Result.—Division of vagi, followed by increased blood-pressure and diminished frequency of the pulse.

TABLE II.—General Results of the Foregoing Experiments on Dogs.

No. of Experiment.	Vagi divided during	Blood-Pressure.	Pulse.
XXXII.	Digestion.	Increased.	Accelerated.
XXXIII.	,,	,,	Unaltered.
XXXIV.	,,	,,	,,
XXXV.	,,	,,	,,
XXXVI.	Fasting.	Unaltered.	,,
XXXVII.	,,	,,	,,
XXXVIII.	,,	Slightly increased.	Retarded.

In all these experiments the cardio-inhibitory nerves were paralysed previous to the division of the vagi.

When these experiments were performed, I was too much influenced by the fact that Ludwig and Cyon* had always failed to find the depressor nerve in action; I therefore fancied that although it is impossible to divide the vagi in dogs without at the same time dividing the nervi-depressores, such experiments might nevertheless serve to show whether or not the gastric and vaso-inhibitory fibres of the vagi are thrown into action during digestion. But, on several occasions in experimenting on rabbits and cats, I have, as before stated (see page 109), had the good fortune to find the nervi-depressores in action—as shown by the rise in the blood-pressure which followed their section. I am therefore convinced that the depressor branches of the vagus are by no

* *Lib. cit.*

means so inactive as their discoverers have concluded, from the small number of experiments performed by them. Seeing, therefore, that these nerves are not unfrequently in action, and seeing that in the dog, as above stated, the trunks of the vagi cannot be divided without at the same time cutting across the depressor nerves, I am compelled to admit that, in the group of experiments on dogs just given, the increased blood-pressure which followed section of the vagi may have resulted from section of the depressor nerves, and from these only. The question at issue must therefore be decided by experiments on cats and rabbits, seeing that in these animals the superior cardiac branch (depressor nerve) leaves the vagus high in the neck, and can therefore be divided separately from the trunk of the latter.* If, however, the results of the foregoing experiments on dogs were due to the action of the depressor nerves, then we should require to adopt the conclusion that these nerves act during digestion, and are inactive during fasting. Such a conclusion is opposed by the results of experiments on rabbits and cats, which are yet to be detailed. There is no evidence whatever that the depressor nerve acts more during digestion than during fasting; and therefore, after all, these experiments on dogs really do support the idea that during digestion vaso-inhibitory fibres, distinct from the "*depressor*" nerve fibres, in the vagus are thrown in action.

The following experiments on rabbits and cats are, however, entirely free from the source of fallacy that obtains in the case of dogs, because in the former animals the nervi-depressores can be divided without the vagi being at the same time implicated.

B. EXPERIMENTS ON RABBITS AND CATS.

(a.) *During Digestion.*

Cardio-inhibitory Nerves paralysed by Atropia.

EXPERIMENT XXXIX.—Strong Rabbit fed at 2 p.m. Canula in Carotid Artery. Trachea open.

Time.	Pulse in 10″.	Mean Pressure in inches of Hg.	General Notes.
3·57′	44	4	
59′			10 milligrammes atropiæ sulph. injected into vein.
30″	44	4·5	
4· 1′			Both depressors divided.
30″	40	4·4	
2′			Both vagi divided.
3′	39	5·5	
4′ 15″	38	5·3	
6′ 20″	38	5·2	
10′	39	5·3	

* The reader will now understand why remarks on the blood-pressure were omitted from the commentary on the first group of experiments on dogs (see page 122).

Result.—Division of vagi followed by increased pressure, but no change in frequency of pulse.

EXPERIMENT XL.—A Strong Rabbit, which had Fasted for Twelve Hours, was Fed at 1·30 P.M. Canula in Carotid. Trachea open.

Time.	Pulse in 10″.	Mean Pressure in inches of Hg.	General Notes.
3· 5′	38	3·5	
6′	38	3·4	
8′	39	3·55	Both depressors divided.
9′			10 milligrammes atropia sulphate injected into vein.
10′ 20″	42	3·5	
11′ 40″			Right vagus divided.
12′ 20″	41	3·7	
14′			Left vagus divided.
16′	46	4·2	
19′ 10″	45	4·4	
21′ 15″	44	4·3	
22′			Cardio-inhibitory nerves still paralysed.

Result.—Division of vagi followed by increased pressure and acceleration of pulse.

EXPERIMENT XLI.—A Strong Rabbit fed at 1 P.M. Canula in Carotid Artery. Trachea open.

Time.	Pulse in 10″.	Mean Pressure in inches of Hg.	General Notes.
3·19′	42	3·3	
20′	43	3·4	
24′			10 milligrammes atropia sulphate injected into vein.
3·25′	52	3·5	
26′ 10″			Both depressors divided.
27′ 40″	47	4·1	
28′ 30″	45	4	
29′ 25″			Right vagus divided.
31′	46	4·2	
32′ 5″			Left vagus divided.
34′	50	4·8	
35′	52	4·7	
38′ 15″	51	4·8	
40′ 35″	50	4·9	

Result.—Increase of pressure and acceleration of pulse following division of vagi.

EXPERIMENT XLII.—Strong Rabbit, fed at 10 a.m. Canula in Carotid Artery. Trachea open.

Time.	Pulse in 10″.	Mean Pressure in inches of Hg.	General Notes.
12· 2′	36	3·6	
4′ 5″	37	3·6	
5′			9 milligrammes atropiæ sulph. injected into vein.
30″	50	3·8	
6′ 15″	46	3·8	
7′ 35″	44	3·6	
8′ 15″	43	3·7	
9′			Both depressors divided.
10′ 25″	42	3·6	
11′ 40″	41	3·7	
13′			Right vagus divided.
14′ 10″	40	3·6	
15′ 20″			Left vagus divided.
17′ 30″	50	4·9	
18′ 15″	51	5	
40″			Cardio-inhibitory nerves proved to be paralysed.
20′ 10″	49	4·8	
22′	47	4·7	
24′ 5″	47	4·8	

Result.—Division of vagi, followed by increased pressure and accelerated pulse.

EXPERIMENT XLIII.—Strong Rabbit, fed at 10.30 a.m. Canula in Carotid Artery. Trachea open.

Time.	Pulse in 10″.	Mean Pressure in inches of Hg.	General Notes.
1·15′	41	4·1	
16′ 10″	42	3·9	
17′ 15″	41	3·9	
18′ 5″			10 milligrammes atropia sulphate injected into vein.
55″	58	4·2	
20′	54	4	
22′ 8″	52	4·1	
23′ 15″	53	4	
24′ 5″			Both depressors divided.
25′ 30″	52	4·1	
26′ 5″	50	3·9	
27′			Both vagi divided.
28′ 30″	54	5·2	
30′	55	5	
34′	54	4·9	
37′ 1″	55	4·9	

Result.—Division of vagi, followed by decided rise in pressure and slight acceleration of pulse.

EXPERIMENT XLIV.—Strong Rabbit fed at 1.5 p.m. Canula in Carotid. Trachea open.

Time.	Pulse in 10″.	Mean Pressure in inches of Hg.	General Notes.
2·56′	34	3·2	
57′ 5″	34	3·1	
58′			10 milligrammes atropia sulphate given.
59′ 30″	58	3·4	
3· 2′	56	3·4	
4′ 5″	54	3·3	
5′ 10″			Both vagi divided.
6′ 20″	52	4·5	
7′ 40″	50	4·4	
10′	45	4·6	
12′	44	4·5	
13′ 10″			Both depressors divided.
50″	45	4·9	
15′	44	4·8	
19′ 45″	42	4·8	

Result.—Division of vagi, followed by increase of pressure and retardation of pulse. Division of nervi-depressores, followed by increased pressure, but by no change in pulse.

The rise in the pressure observed in this group of experiments was certainly not due to any voluntary muscular movements on the part of the animal. In all cases, none of the recorded observations were made during struggling or other violent movements, unless it is so stated in the General Notes. In order, however, to satisfy all that this increase of blood-pressure is really due to a change in the state of the vascular system not dependent upon extraneous muscles, I performed the following experiment, in which, in addition to the atropine, I gave curara, in order to paralyse all voluntary movement.

EXPERIMENT XLV.—Strong Rabbit Fed at 11 a.m. Canula in Carotid Artery. Trachea open.

Time.	Pulse in 10″.	Mean Pressure in inches of Hg.	General Notes.
1·28′			8 milligrammes atropia sulphate injected into vein.
35′	46	3	
37′	44	2·75	
44′			2 milligrammes curara injected into vein.
47′	44	2·8	
48′ 30″	41	2·7	
49′			Both depressors divided.
51′	42	2·8	
52′ 10″			Right vagus divided.
53′	43	3	
30″			Left vagus divided.
54′ 20″	42	4·2	
55′ 40″	41	4·1	
57′	40	4·2	
59′ 10″	43	4·3	
2· 2′	40	4·1	Cardio-inhibitory nerves still paralysed.

Result.—Division of vagi followed by rise in blood-pressure, but by no change in frequency of pulse. The animal having been paralysed by curara as well as by atropine, this rise in pressure cannot be ascribed to anything but a change within the vascular system independent of extraneous muscular movements.

EXPERIMENT XLVI.—A Full-Sized Cat Fed at 2.20 p.m. Canula in Carotid. Trachea open.

Time.	Pulse in 10″.	Mean Pressure in inches of Hg.	General Notes.
4·40′	30	4·5	
45′			5 milligrammes atrop. sulph. injected into vein.
30″	38	4	
47′			Both depressors and cervical sympathetics divided.*
48′	36	5·1	
49′ 30″	36	5·1	
52′			Both vagi divided.
53′	39	6·4	
58′	39	6·3	
5· 1′ 10″	38	6·2	
4′	39	6·4	
5′ 30″			Cardio-inhibitory nerves still paralysed.

* In the cat the depressor nerve usually joins the trunk of the sympathetic soon after leaving the vagus in the upper part of the neck. It is, therefore, most convenient to divide both sympathetic and depressor.

Result.—Division of vagi and depressors followed by increased blood-pressure; but no change in the frequency of the pulse.

(b.) *During Fasting.*

EXPERIMENT XLVII.—Strong Rabbit which had Fasted for Eighteen Hours. Canula in Carotid Artery. Trachea open.

Time.	Pulse in 10″.	Mean Pressure in inches of Hg.	General Notes.
12·28′	38	4	
30′	38	4	
32′			8 milligrammes atropia sulphate injected into vein.
35′	57	3·6	
36′	55	4·2	
37′			Both nervi-depressores divided.
30″	54	4·3	
38′			Right vagus divided.
45″	53	4·2	
40′	51	4·1	
41′			Left vagus divided.
42′	50	4	
44′	49	3·9	
45′	50	3·9	

Result.—Division of vagi followed by no change in pressure or pulse.

EXPERIMENT XLVIII.—Rabbit which had Fasted for Eight Hours and a Half. Canula in Carotid Artery. Trachea open.

Time.	Pulse in 15″.	Mean Pressure in inches of Hg.	General Notes.
4·54′	48	3·8	
56′	50	4	
5·10′			9 milligrammes atropia sulphate injected into vein.
13′	74	3·8	
15′	76	3·6	
18′	74	3·5	
30″			Both depressors divided.
20′	75	3·5	
21′			Both vagi divided.
27′	77	3·4	
30′	74	3·5	
32′	70	3·6	
34′ 10″	68	3·4	

Result.—Division of vagi followed by no change in pressure or pulse.

EXPERIMENT XLIX.—Strong Rabbit which had fasted for nine hours. Canula in Carotid Artery. Trachea open.

Time.	Pulse in 10″.	Mean pressure in inches of Hg.	General Notes.
3·58′	40	3·9	
4· 4′	41	4·2	
5′			10 milligrammes atropia sulphate injected into vein.
7′ 15″	54	3·7	
8′ 20″	52	3·9	
9′ 30″			Both depressors divided.
11′ 15″	51	3·8	
13′			Both vagi divided.
14′ 45″	58	3·7	
16′ 20″	49	3·8	
19′	48	3·8	

Result.—No change in pressure or pulse followed division of vagi.

EXPERIMENT L.—Strong Old Rabbit which had fasted for sixteen hours. Canula in Carotid Artery. Trachea open.

Time.	Pulse in 10″.	Mean pressure in inches of Hg.	General Notes.
11·30′ 25″	48	4·5	
32′	47	4·4	
33′			10 milligrammes atropia sulphate given.
34′	49	4·5	
36′ 18″	48	4·6	
37′			Both depressors divided.
39′ 15″	47	4·8	
41′			Right vagus divided.
42′ 35″	48	4·7	
45′			Left vagus divided.
48′ 20″	47	4·8	
50′	48	4·7	
54′ 5″	48	4·5	
57′	46	4·6	

Result.—Division of vagi followed by no change in pressure or pulse.

EXPERIMENT LI.—Strong Rabbit which had fasted for eighteen hours. Canula in Carotid Artery. Trachea open.

Time.	Pulse in 10″.	Mean pressure in inches of Hg.	General Notes.
4· 6′	44	4·5	
8′			8 milligrammes atropia sulphate given.
9′ 30″	46	4·6	
11′ 45″	47	4·5	
12′			Both depressors divided.
13′ 15″	50	5·8	
14′ 5″	49	5·6	
16′			Blood coagulated. Canula cleaned.
20′	45	5·2	
21′ 20″			Both vagi divided.
24′	46	5·2	
28′	45	5·2	
30′	46	5·3	

Result.—Section of vagi followed by no change in pulse or pressure. Section of superior cardiac branches of vagi followed by increased pressure and temporary acceleration of pulse.

EXPERIMENT LII.—Strong Rabbit which had fasted for twelve hours. Canula in Carotid Artery. Trachea open.

Time.	Pulse in 10″.	Mean pressure in inches of Hg.	General Notes.
3·35′	40	3·8	
36′			8 milligrammes atropia sulphate given.
30″	50	3·5	
38′	50	3·7	
40′			Both depressors divided.
45″	49	3·6	
43′	50	3·7	
44′			Both vagi divided.
45′	54	4·1	
46′ 20″	52	3·9	
49′ 10″	50	3·7	
53′	48	3·8	

Result.—Division of vagi followed by a transient rise in pressure and pulse. This was probably due to excitement, seeing that it soon disappeared.

EXPERIMENT LIII.—A Large Strong Cat which had fasted for thirteen hours. Canula in Carotid Artery. Trachea open.

Time.	Pulse in 10″.	Mean pressure in inches of Hg.	General Notes.
9·20′	32	3·6	
22′	33	3·5	
23′			5 milligrammes atropia sulphate given.
30″	40	3·7	
25′	41	3·8	
28′			Both depressors and cervical sympathetics divided.*
29′ 30″	40	3·7	
32′			Both vagi divided.
33′ 25″	38	3·8	
35′ 15″	39	3·9	
38′	37	3·8	
40′ 5″	38	3·9	

Result.—Division of vagi followed by no noteworthy change in pulse or pressure.

The general result of the foregoing experiments on rabbits and cats may be learned from the following table.

TABLE III.—General Results of the Foregoing Experiments on Rabbits and Cats.

No. of Experiment.	Nature of Animal.	Vagi divided during	Blood-Pressure.	Pulse.
XL.	Rabbit.	Digestion.	Increased.	Accelerated.
XLI.	,,	,,	,,	,,
XLII.	,,	,,	,,	,,
XLIII.	,,	,,	,,	,,
XLIV.	,,	,,	,,	Retarded.
XXXIX.	,,	,,	,,	Unchanged.
XLV.	,,	,,	,,	,,
XLVI.	Cat.	,,	,,	,,
XLVII.	Rabbit.	Fasting.	Unchanged.	,,
XLVIII.	,,	,,	,,	,,
XLIX.	,,	,,	,,	,,
L.	,,	,,	,,	,,
LI.	,,	,,	,,	,,
LII.	,,	,,	,,	,,
LIII.	Cat.	,,	,,	,,

In all these experiments the cardio-inhibitory nerves were paralysed previous to the division of the vagi.

* See note to Experiment XLVI.

These experiments (XXXIX.–LIII. inclusive) show,—

1*st.* That in rabbits division of the vagi may be followed by increased blood-pressure and accelerated pulse, although the cardio-inhibitory nerves are paralysed, and therefore totally inactive before the division of the nerves.

2*d.* In experiments XXXIX., XLV., XLVI., the pulse was unaffected by the section: in experiment XLIV. it was retarded, and, notwithstanding, the blood-pressure was increased in all these cases. A rise in the blood-pressure following division of vagi may therefore be quite independent of the heart.

3*d.* The blood-pressure was unaffected when the vagi were divided during fasting, while it rose after their section during digestion. When we remember that when the vagi are divided during digestion a permanent blanching of the stomach takes place (see p. 126), it is evident that the rise in pressure in the experiments under consideration must be ascribed to contraction of gastric vessels chiefly if not entirely. It therefore appears that the increased blood-tension which frequently follows division of the vagi cannot—as has hitherto been supposed—be wholly ascribed to increased action of the heart liberated from its inhibitory nerves (see p. 120). Instead of depending only on one factor it really depends on two. Cessation in the action, 1st, of cardio-inhibitory; and 2d, of vaso-inhibitory fibres of the vagi.

4*th.* The evidence afforded by these experiments and those previously given (see page 126), shows that during digestion inhibitory influences pass from the stomach through the vagi to paralyse those vasomotor cells in the medulla which preside over the gastric blood-vessels. But during fasting, when the gastric blood-vessels are in a contracted state, both the vaso-inhibitory and excito-vasomotor fibres of the vagi are at rest. (Were the latter in an active state, a fall in the blood-pressure would follow division of the vagi during fasting). It appears, therefore, that although the vaso-inhibitory fibres of the vagus play an important part in dilating the gastric blood-vessels, the rôle assigned to the gastric excito-vasomotor fibres of the vagi is as yet unknown. Vasomotor nerve-cells appear, like their homologues the cells of the cardiac ganglia, to be continually evolving energy. By reason of this, they would constantly keep the blood-vessels in at least a semi-contracted state, were it not that their power of generating energy may be controlled by inhibitory nerves. These nerves appear to be brought into play by the tissues of a part when it demands a greater influx of blood, but when it has no such demand, it does not appear that the excito-vasomotor nerves are brought into action to increase the evolution of force in the vasomotor nerve-cells, but it seems that in this case the tissues simply cease to excite vaso-inhibitory nerves. I am, therefore, inclined to think that these excito-vasomotor nerves discharge their functions on occasions much more extraordinary than those on which the vaso-inhibitory fibres operate; but what those are must be left for future research to determine.

5th. Although in all the experiments the pulse remained unchanged when the pressure underwent no alteration after division of the vagi, it was variously affected when the pressure was increased. In four cases (see Table III.) it was accelerated, in three it remained unchanged, while in one it was retarded. Seeing that the acceleration in these cases and in those previously given (see page 120) took place when the cardio-inhibitory nerves had been paralysed previous to the section of the vagi, it is certain that it could not be due to escape of the heart from control. To what cause, then, shall we ascribe it? I can think of none other than a direct influence of the increased blood-pressure upon the lining membrane of the heart. It is now generally agreed that—as LUDWIG and THIRY* pointed out—*if the vagi have been previously divided*—that is, if the cardio-inhibitory nerves are not in operation, increased blood-pressure usually accelerates and very rarely retards the pulse.† The retardation is commonly the result of an extraordinary increase of the pressure. My experiments on this question have convinced me of the truth of the above, but I have, moreover, frequently noticed that a considerable rise in the blood-pressure may take place without causing any change in the rapidity of the heart's action. As these results are all illustrated in Table III., I therefore think that in the first five experiments there recorded, the acceleration and retardation of the pulse were due to the increased blood-pressure. Whether this be or be not the true explanation, it is certain that the acceleration of the pulse which so frequently follows section of the vagi, is not, as is generally supposed, dependent merely on escape of the heart from the influence of its controlling nerves, but depends on at least another cause—and that probably is—a rise in the blood-pressure. Seeing that such is the case, the amount of acceleration of the pulse which may follow division of the vagi, cannot any longer serve as an accurate index to show the extent to which the cardio-inhibitory fibres of the vagi may be in action previous to their section, indeed we have as yet no accurate test by means of which this may be ascertained. It has, indeed, been stated by Von BEZOLD, that a trustworthy test is to be found in the action of atropia. Most of my experiments show that when sulphate of atropia is administered previous to division of the vagi, a varying degree of acceleration of the pulse almost always ensues. It has been said by the above-named author‡ that this acceleration is entirely due to palsy of the cardio-inhibitory nerves—the heart simply attaining the speed which it would maintain but for the inhibitory action of these nerves. Von BEZOLD came to this conclusion from observing that atropia never accelerates

* WIENER, Sitz. Berichte, 1864, Band 49.

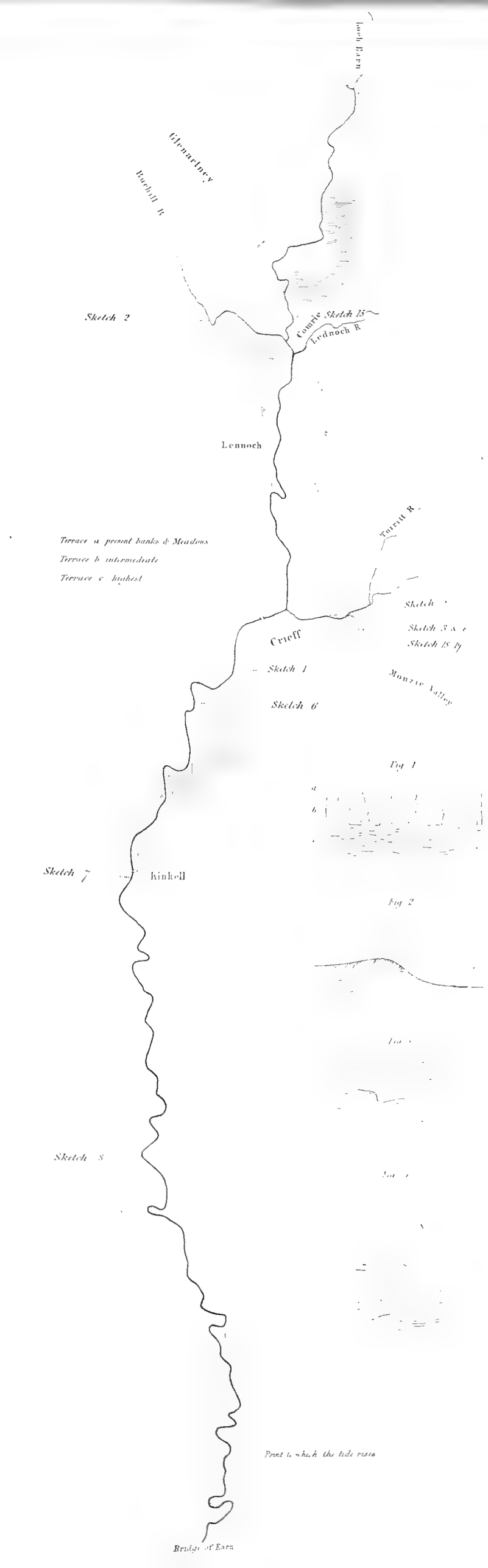
† Much confusion has been produced by certain authors discussing the influence of the blood-pressure upon the cardiac movements without distinguishing between the influence of the pressure before and after section of the cardio-inhibitory nerves.

‡ Von BEZOLD. Untersuchungen aus dem physiologischen Laboratorium. Würzburg, 1867, Erstes Heft.

the pulse if it be given *after division* of the vagi. Unhappily this is untrue. I have more than once noticed that if atropia sulphate be administered to rabbits and dogs after division of the vagi, a decided acceleration of the pulse was the result. For example—

Experiment LIV.—I divided the vagi of a rabbit, and after waiting five minutes, I counted the pulse and found it 228 in the minute. I then very slowly injected 50 milligrammes of atropia sulphate dissolved in one cubic centimetre of water into the jugular vein. The speed of the pulse at once rose to 258 in a minute. Ten minutes afterwards the pulse was 240 in the minute. I then gave another dose of 25 milligrammes atropia sulphate dissolved in half a cubic centimetre of water. The pulse very rapidly rose to 270. The blood-pressure was slightly diminished by these doses. It therefore appears that atropia may stimulate the cardio-motor nerve apparatus as well as paralyse the cardio-inhibitory nerves, and so we cannot trust this substance to indicate the times of action and inaction of the cardio-inhibitory nerves.

Much that is obscure yet remains in connection with the innervation of vascular system, but I venture to think that the researches detailed in the foregoing communication clear away not a little fallacious dross from this matter, while they likewise fill up some important blanks, and thereby render more complete our knowledge of this complicated and recondite subject.


Loch Earn
Glenartney
Ruchill R
Sketch 2
Comrie Sketch 15
Lednoch R
Lennoch
Turrid R
Terrace a present banks & Meadows
Terrace b intermediate
Terrace c highest
Sketch
Sketch 3 a c
Sketch 18 b
Crieff
Sketch 1
Monzie Valley
Sketch 6
Fig 1
a
b
c
Sketch 7
Kinkell
Fig 2
Sketch 8
Point to which the tide rises
Bridge of Earn

VIII.—*On the Old River Terraces of the Earn and Teith, viewed in connection with certain Proofs of the Antiquity of Man.* By the Rev. Thomas Brown, F.R.S.E. (Plate IV.)

(Read 3d January 1870.)

Introductory.

No subject of modern scientific inquiry is more important than the series of deposits in which geology comes in contact with the period of human history. This must be my apology for some of the seemingly trivial details contained in the following paper. When these observations were begun, nothing could be further from my thoughts than any reference to the antiquity of man. But I shall perhaps best introduce the subject by simply narrating the way in which I was led forward step by step, till the whole inquiry assumed the form in which it is here presented.

In the autumn of 1863, I spent some weeks at Bridge of Earn, on the estuary of the Tay, and noticed, as every one must, the carse lands lying along the river Earn, from which they rise by a steep escarpment, running on a dead level back to the base of the hills. They were deposited, our recent geological authorities* say, at a time when the land stood lower and the sea higher than now, and are the estuarine mud of that former period. I had no idea of questioning this opinion, or of examining the deposit, but in my walks I was struck by the marked absence of marine fossils. Long ranges of sections were beautifully laid open, and the absence of marine organisms seemed so remarkable that I was led to make a closer examination. In the deposit I found there were two divisions, a lower and a higher, separated by a bed of peat about a foot in

* It may be enough to refer to a series of papers from 1860 to 1866 in the Journal of the Geological Society of London, by Mr Jamieson, of Ellon, forming one of the most valuable contributions made of late years to Scottish geology, and one frequently quoted and relied on by Sir C. Lyell. I give two quotations :—

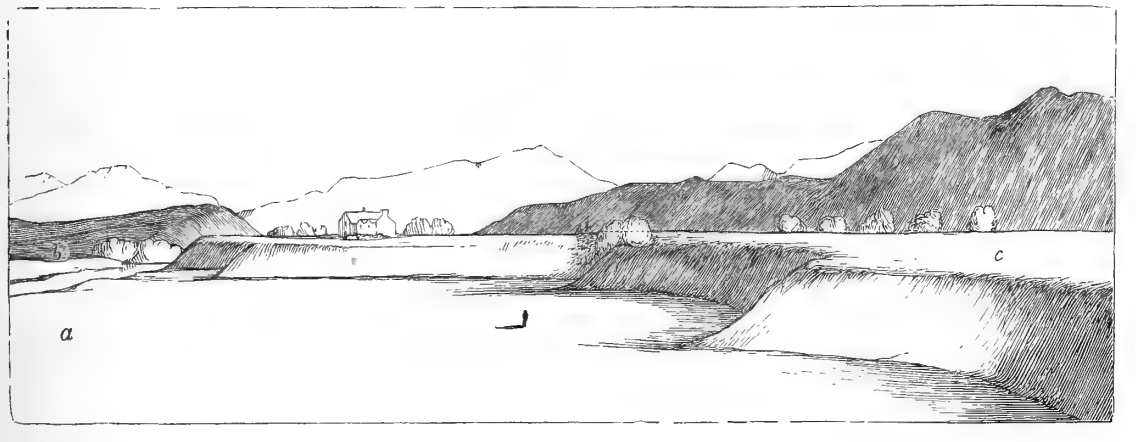
"The land sank again until the sea in most places reached a height of from 30 to 40 feet above the present tide-mark. . . . . The clays and beds of silt forming the carses of the Forth, Tay, and other rivers were accumulated."—1860. Vol. xvi. p. 371.

"A depression now took place. . . . . In the valley of the Tay and Forth this old coast-line was 25 or 30 feet above the present, but on the coast of Aberdeenshire, not more than 8 or 10. The old estuarine beds or carses of the Forth, Tay, and other rivers were formed, together with corresponding shingle beaches and caves along the coast."—1865. Vol. xx. p. 195. In this paper the deposits of the Earn are specially described.

thickness, which ran for miles through the sections. Taking the order of succession as it usually occurs, we find the following series:—Immediately beneath the surface soil (sometimes 3 to 4 feet), there is the carse clay from 9 to 10½ feet in thickness, grey-coloured, tenacious, unlaminated, intermingled with sand towards the base. Underlying this is a stratum of peat, the materials of which seem to have been drifted from some distance, and one remarkable thing is that the leaves, &c., which form this peat are found passing up into the clay, plentifully intermixed with it at first, but getting less abundant as you ascend. The clay and peat are in this way so associated that one might almost view them as forming a single deposit. The portion of the series which underlies the peat consists of laminated clay with partings of sand, and laminated sands with partings of clay, going down under the surface of the river. This lower series is unconformable to the overlying peat and clay, and occasionally the former surface is seen to have been denuded, and the peat and clay are found filling up the hollows. Some miles further up, near the railway station at Forgandenny, the sandy layers are found to predominate, with small gravel intermixed, and the whole has been consolidated into a tolerably compact sandstone conglomerate, two yards of which are exposed at the base of the cliff underlying the peat. In regard to the peat itself and the immediately overlying clay, it is found everywhere to contain wood, marsh plants, such as the *Arundo phragmites*, hazel-nuts, mosses, &c. At one point I found a series of leaves—willow, plane, &c.—in a singular state of preservation, spread out between laminæ of clay, displayed as in a herbarium, and this continued layer after layer for a yard above the peat. The hazel-nuts which occur in the peat are of a large size, and still show something of the shining brown colour which belongs to them. There are occasional specimens of beetles also, the elytra of which retain much of their brilliancy. My examination of these deposits was by no means complete, but their general character seemed sufficiently obvious. What was to be said in favour of their marine or estuarine origin I really could not tell. No single trace of any marine organism would turn up. For miles and miles the deposit was laid open, but examine it where you might, all the remains were fresh-water or land. The evidence was indeed to a great extent negative, and I was not willing to come to any definite conclusion, but everything seemed to indicate that these beds were merely a river formation. They rise about 27 feet above the present level of the stream. If only we could suppose a time when the river floods had, like those of the Nile, the power of rising 27 feet, how natural and how easy the explanation of the whole phenomena would be.

Next autumn (1864) I went to Crieff, further up the Earn. Even on approaching the town, looking through the windows of the railway carriage, I was struck

by the resemblance of the high banks lying along the river to those already observed at Bridge of Earn. The general aspect of these terraces is well shown in the sketch here given, where *a* represents the level of the present banks of the river, *b* an intermediate terrace on the opposite side, and *c* the high level terrace. This last was obviously a formation similar to what I had seen the previous year. It lay more than 100 feet higher above the sea than that at Bridge of Earn. The only agent holding the same relation to it in both localities was the river, along which lay the steep escarpment and level surface, telling in each case the same story. And again the question presented itself, was not this simply a river formation in *both* cases? might not the sea have as



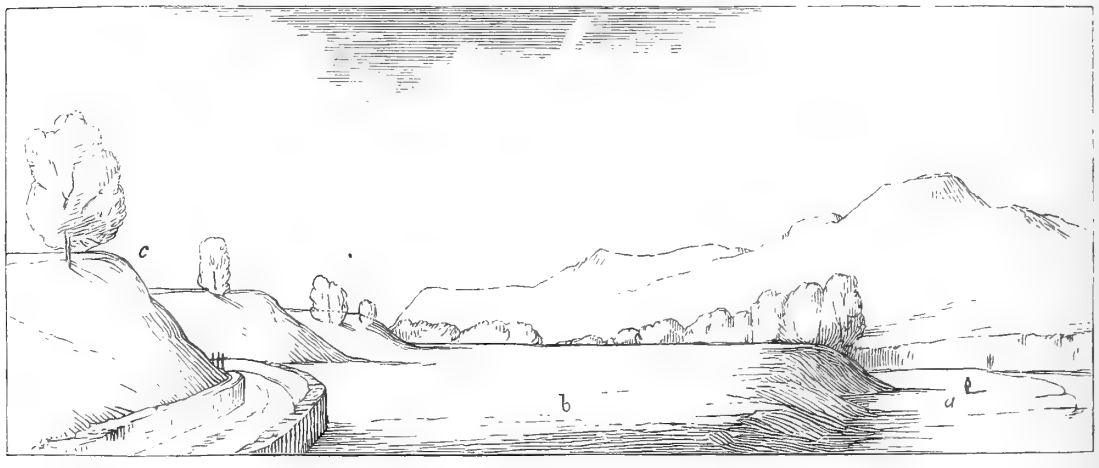
Sketch 1.—Near Crieff.

little to do with that deposit at the Bridge of Earn as in the neighbourhood of Crieff? I had long felt, however, that much time and attention would be required for the satisfactory examination of these river deposits. Men had too often been content to take a bit here and a bit there from different river-courses, without the continuous examination of any one in particular. If reliable results were to be reached, it seemed that some one of our rivers must be fixed on, followed from the hills to the sea, and made to tell its story from end to end. This was the more apparent on comparing the deposit at Crieff with that at Bridge of Earn. But such an examination demanded more time than was then at my disposal.

The succeeding season I spent some weeks at Comrie, still higher up the Earn, and there the same deposits again presented themselves in a form which seemed still more to deserve investigation in connection with the carse lands at the mouth of the river.

I had gone one day to the foot of Glenartney, near Cultibregan, where the Ruchil flows from the hills down on the plain of Dalginross. Looking up the

valley there appeared three terraces, as represented in sketch 2.* Along the river side is the lowest terrace, *a*, about six feet above the water, being the height of the present banks. Further back, and rising above it, is the second terrace, *b*, about sixteen feet higher than the first, or twenty-two feet above the water; and still further back is the third, running along the sides of the valley, its level being, at the point where I measured it, about 57 feet above the bed of the stream. In this last the line of escarpment has been somewhat broken by denudation, but the continuity of the terrace itself is obvious at a glance. The whole of these levels consist of gravels and sands with clay in



Sketch 2.—Near the Foot of Glenartney.

different proportions. Near the point *c*, the highest terrace was well laid open, and showed the following structure, beginning at the surface :—

	Feet.	Inches.
1. Gravel with clay, the pebbles lying on their flat sides,	2	0
2. Pan,	0	1
3. Gravel, sandy above, coarser beneath,	2	3
4. Fine brown sand, in layers,	0	8
5. Fine gravel with sand,	depth unknown.	

This was evidently the work of running water, and the question again arose whether it had not been deposited by the river at some period when its floods ran much higher than at present, and whether that threefold system of terraces might not be found to throw light on the whole of these old river deposits. On going across to the Turrit, where it comes out from the hills

* For this series of sketches I am indebted to a young friend, Mr W. B. Murray, an art-student of our Edinburgh School, who has been very successful in his rendering of the scenes. Along the Earn it has, in three or four cases, been necessary to suppose the woods thinned, in order to show the real form of the ground, but this has been done as sparingly as possible. On the Teith there was less need for this except in Sketch 12, and even on the Earn all the finest examples of the terraces, such as those in Sketches 6 and 7, are given exactly as they appear in nature.

below Ochtertyre, I found the same three levels in still more striking proportions, and it at once became a question how far they could be continuously traced along these river valleys.

Beginning at the foot of Glenartney there could be no doubt as to the lowest level forming the present banks of the river. It passes downwards and spreads out into extensive meadows. And equally marked was the extension of the second terrace, the steep escarpment of which goes sweeping for miles, forming a great irregular triangle from Cultibregan to Lennoch, the level flatness of the surface being not less remarkable than that of the Carse lands at Bridge of Earn. The highest terrace, however, is often discontinued, especially along the right bank of the river; but away to the north, beginning at Coneyhill, portions of it may be seen at Tomperran, Lawers, and especially at Monzievaird. It soon became apparent that these terraces were a good deal interrupted, appearing and disappearing by turns, while at intervals the threefold system is in full preservation. But these interruptions are not to be wondered at, when we think of the denuding agencies to which the deposits were exposed. The loose sands and gravels, of which they were composed, were just the materials most liable to be washed away, and their position on the sloping sides of the valleys was precisely that on which the denuding agencies would most powerfully act. It is plain also, that the rains and floods of the old time were much more powerful than now, and, if we picture them to ourselves, rising to a height and acting with a force to which nothing at the present day can be compared, it is little wonder that the terraces have in many places been removed, and in others greatly worn down and obscured.

Making fair allowance for all this, it became a question whether anything like a continuous chain of these deposits could be traced along the course of the valley. During the autumn of 1865, and again in 1866, I had some weeks of leisure on my hands, and I thought something might be done to ascertain the point. Taking the Ordnance Survey map in my hand, I filled in as I went along the results of my observations, using a separate colour to mark each of the three levels. At all points of importance I endeavoured to ascertain, from actual sections, the internal structure of the terraces, for there is always a risk of mistaking for a terrace what is really due to the rocky structure of the country. I took also a series of measurements showing the height of the deposits above the river course; but being alone I had to content myself with only approximate results. Thus, I followed the Earn, from where it leaves the loch to where it meets the tide, through many pleasant days, amidst scenes of quiet river-side beauty, which I shall not soon forget. The results are given in the accompanying map (Plate IV.) That I have succeeded in all cases in reading the deposits aright, or in tracing their boundaries, is, I am afraid, more than I can hope for. I offer it merely as an approximative eye-sketch,

sufficient, I believe, to show the general course of these deposits. Their outline on the side furthest from the river is not attempted.

Having thus examined the Earn, it seemed desirable to test these views in some different district; and next summer (1867), accordingly, I went to Callander, on the banks of the Teith, the chief stream in the basin of the Forth. From the details about to be given it will be seen that the same terrace system is developed along the Teith, if possible, more strikingly than I had seen it on the Earn. Other occupations made it impossible for me at once to follow up the subject, but, having during last autumn verified the leading points, I shall now endeavour to state the results.

Origin of the Terraces.

The great point of interest is the question as to how these terraces were formed, and I go into the discussion of this the more willingly, because it will lead me to describe the way in which these deposits occur, and will show their continuity along the different valleys.

One explanation ascribes their formation to the sea at a time when the land was to a great extent submerged, and when our river courses were fiords. These terraces, it is said, are the old shores, against which the tides rose and fell. Great prominence has been given to this view by various writers, and especially by Dr Robert Chambers in his work on "Ancient Sea Margins," part of which refers to the Tay and its tributaries.* There is one difficulty, however, in the way of this opinion, from the utter absence of marine fossils. Even where the most delicate leaves of land plants are beautifully preserved we can find no trace of the sea. Another difficulty lies in the impossibility of conceiving how the threefold terrace system could have been formed by marine action. The sea can lay down only one line of beach at a time. Take the valley, sloping upwards for 240 feet from Bridge of Earn to the foot of Glenartney,—suppose it once filled by the waters of the sea, and that they gradually retired, leaving, as they went, the highest terrace, how is the second terrace to be formed? Will you let down the land, reintroduce the sea, and bring it again to the foot of Glenartney? But what would become of the highest terrace, in the meantime, all down the valley, at Kinkell for example? Exposed to tides and waves, must it not have been swept away? There is yet another difficulty, not less fatal, to which we shall immediately refer.

Some of our leading geologists, rejecting this view, have held these terraces to be the margins of ancient lakes. The flow of the waters, it is said, had been barred, and our valleys had become the beds of old lakes. From time to

* Nowhere, perhaps, is this opinion more ingeniously stated and defended than in a series of papers by the late Mr Charles Maclaren. See his Select Writings recently published, vol. ii. pp. 186–201. It is from the valley of the Tay that he takes his examples.

time the barriers had been lowered, and as the waters fell these terraces are the old lake margins showing the different heights at which the waters once stood.*

One fatal objection which applies equally to this view and to the theory of their marine origin, is that these terraces lie up and down the valley not horizontally, but according as the bed of the stream rises and falls. The parallel roads of Glenroy are an example of how it would have been if they had been formed either by the sea or by the standing waters of a lake. In Glen Roy they lie on a horizontal level, keeping their own height without regard to the bottom of the valley. On the Earn, however, the case is reversed; the terraces follow the inclination of the river bed ascending as it ascends towards the hills, descending as it descends towards the sea. Take the intermediate terrace, for example, on which lies the Roman Camp south of Comrie. Beginning at a point above Cultibregan we can trace it as it spreads out and goes down to Lennoch three and a half miles below. To the eye it seems to lie on a dead level; and yet, as shown by the Ordnance Survey, it has a decided incline, being 71 feet higher at Cultibregan than it is at Lennoch, while its height above the river bed is nearly the same. The river course appears to have descended about 68 feet, so that the two have nearly kept pace with each other, and the same thing is found all along the valley. The terraces descend as the river descends from where they leave the hills to where they meet the tide.

This is of course decisive, but the true nature of these deposits can only be fully understood when one follows them continuously from point to point along the whole river valley. There are localities, it must be confessed, where to an ordinary spectator the theory of lake margins would suggest itself as exceedingly probable. Near Strowan, for example, under the hill on which stands the monument to Sir David Baird, the river passes through a gorge, and looking up along its course you see the terrace-like deposits lining the wide open valley on either side, one of them bearing on its surface the church of Monzievaird. Would not one naturally say that the gorge had once been barred and a lake formed, of which these are the old margins? But the fallacy of this is seen

* As this paper deals only with a question of local geology, I do not refer to any writers except those who have treated of the two rivers to which these researches are confined.

Mr Milne-Home applies this explanation of Lake Margins to the Terraces of the Teith, Trans. Roy. Soc. of Edin., vol. xvi. p. 416.

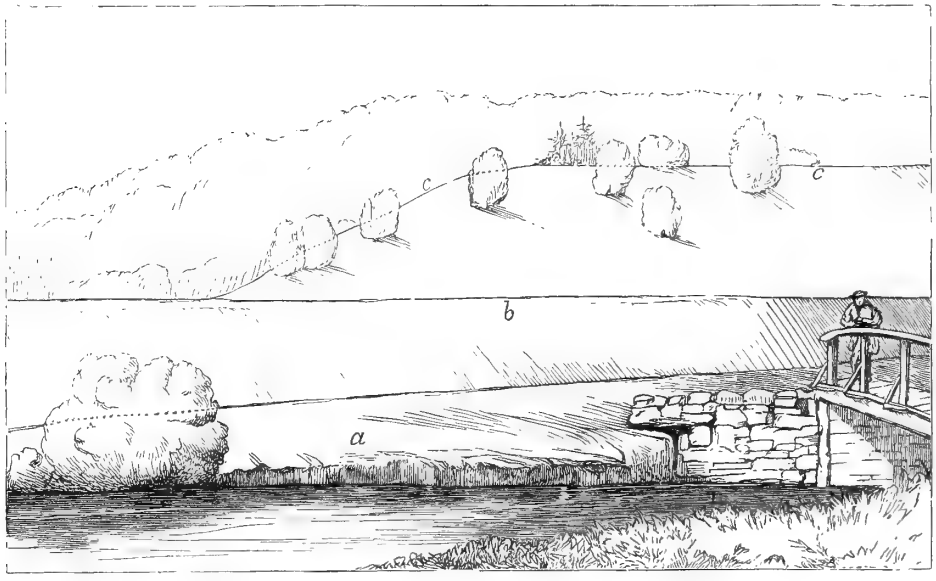
Dr Fleming supposes a lake to have occupied these river valleys, Lithol. of Edin. p. 76, 1859.

I may refer also to a discussion before the Geol. Society of Edin., 19th March 1867, the report of which appeared at the time. Only two theories, the Lacustrine and Marine, found support.

Mr Charles Nicolson, M.A., B.Sc., read a paper on the Surface Formations of the Tay at Perth, describing the Terraces, and advocating the view that they are of Lacustrine origin.

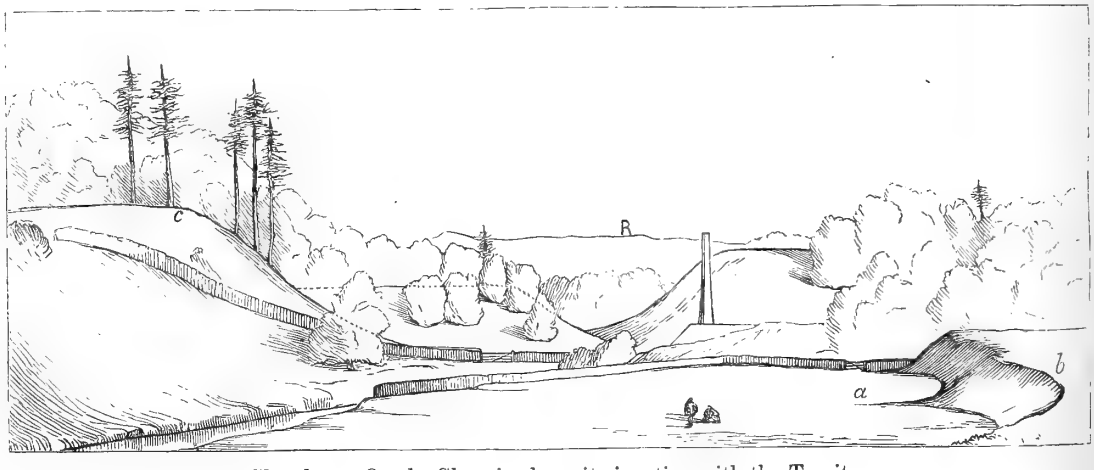
The President Dr Page, Mr Coyne, C.E., and others, gave "their opinion on these Terraces in opposition to Mr Nicolson's Lacustrine Theory maintaining their marine origin, Dr Page instancing the minute examination by Dr R. Chambers of the old sea margins, and Mr Coyne giving his opinion from minute measurements and personal observations."

when you pass through the gorge to the lower side of the supposed barrier, and find portions of the same terraces on the farm of Trowan, thus holding on their course utterly disregarding the supposed limits of the lake. Another instance, to which, as will be seen, some importance attaches, occurs on the Turrit, and especially on the side valley that goes up towards Monzie. In the angle



Sketch 3.—On the Shaggie above its junction with the Turrit.

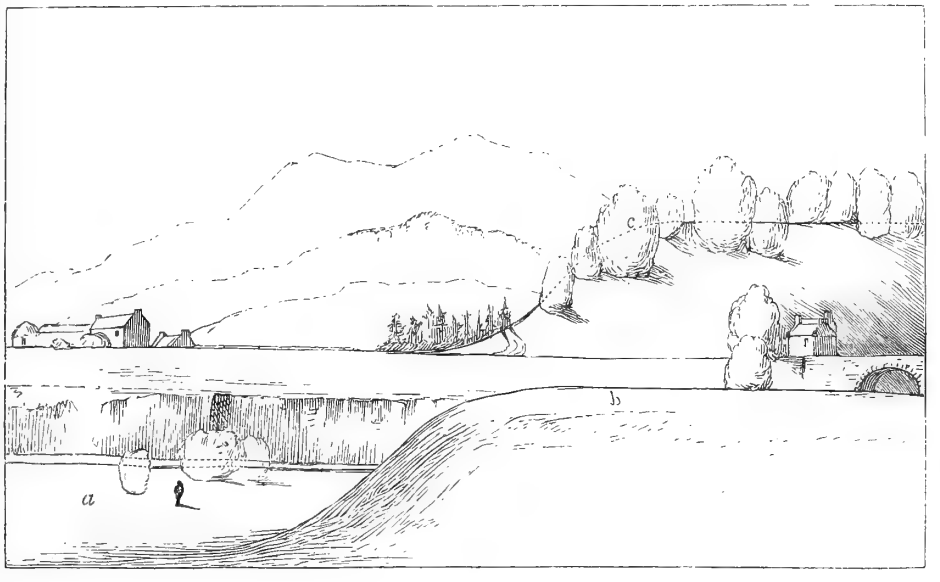
between the two we have the three terraces strikingly developed as represented in sketch 3, where, however, a row of bushes and trees are supposed to be removed, in order that the form of the ground may be seen.



Sketch 4.—On the Shaggie above its junction with the Turrit.

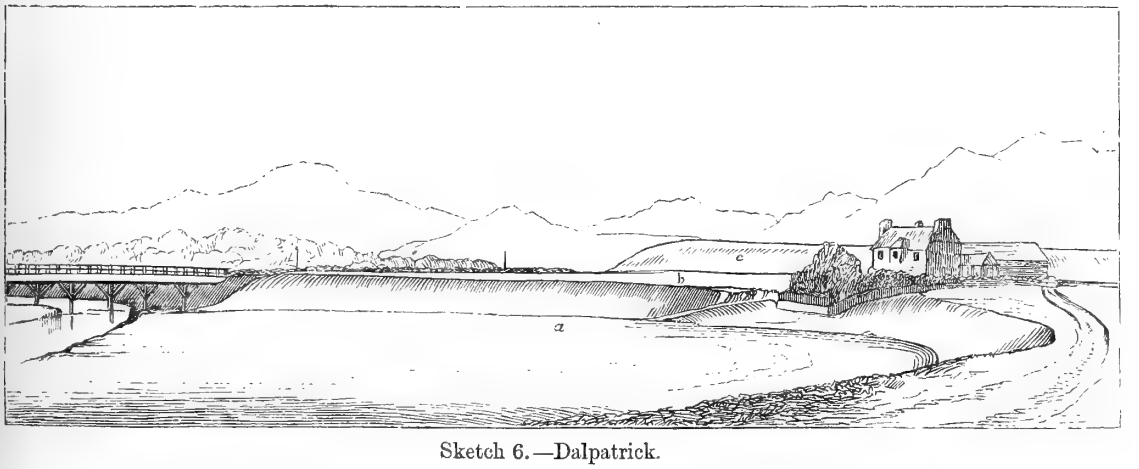
Supposing the spectator to cross the bridge shown in sketch 3, and ascend the second terrace *b*, then turn and look down the stream, he would have before him the view given in sketch 4.

Here we have in front the narrow ravine between the spectator and the point R through which the stream passes; and we might have argued that the glen had once been closed, a lake formed, and that these terraces are the former margins. But following the course of the deposits we find the terrace *c* passing into the ravine and continuing especially along the right bank. And



Sketch 5.—Dalvreck Bridge on the Turrit.

what is more decisive, if you go to the other end and look across and up the glen where the water comes out from under the Bridge of Dalvreck, the three terraces come out distinctly as here given in sketch 5. On the one bank the



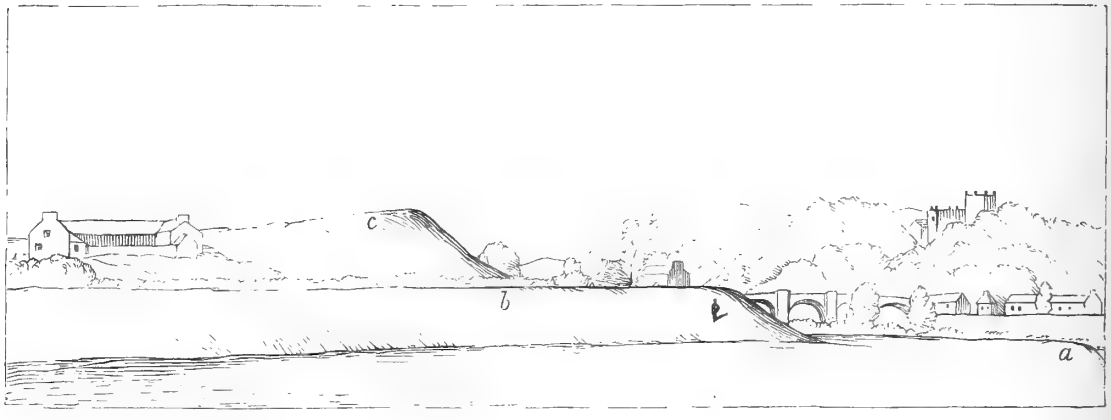
Sketch 6.—Dalpatrick.

second level *b* holds its course at a similar height above the river bed, while in the other bank the highest level *c* passes* out into the open going round

* There is a beautiful section showing that it consists of finely laminated sands with a little gravel and clay.

over the grounds of Ochtertyre; and when one finds these deposits in the same position above the ravine and below it, it seems vain to ascribe them to some lake formed by the barrage of the river.

Tracing the course of the Earn from Crieff to Dalpatrick, we again reach a point above the old castle of Innerpeffray where the channel is narrowed between high grounds. Standing near Easter Dalpatrick and looking upwards, we have the scene as represented in sketch 6. The present banks and meadows, *a*, are surmounted by the second terrace *b*, and that by the higher level *c*, all in full preservation.* Again, the idea might be suggested of a bar above Innerpeffray forming a lake, but again the explanation is forbidden by the continuous course of the deposits, and more especially by their appearance when the narrow portion of the river has been passed, and the banks again spread out into a wide open valley. This takes place immediately below Kinkell, where the threefold terrace system is very remarkable, as shown in sketch 7.



Sketch 7.—Kinkell Bridge, looking up.

A section of terrace *c*, on the eastern side of the Machany, is laid open by the cutting of the road, and is given in Pl. IV., fig. 1. The details are—

a, Humus.

b, Carse clay, grey, unlaminated tenacious.

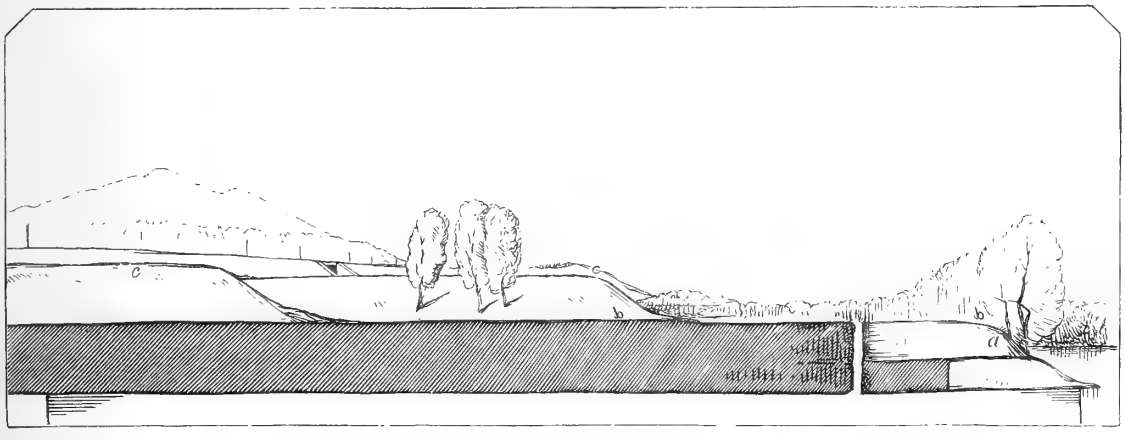
c. Laminated clay with partings of sand. Laminæ a half inch in thickness.

The series of deposits at this point are specially important, because there is no position further down the valley where it is possible to suppose that a barrier could have ever been thrown across. These are not lake margins.

The lower portions of the river, as it passes Dunning, Forteviot, &c., were examined somewhat more rapidly. The threefold system of terraces seems to have been less distinctly preserved. A point, however, is given in sketch 8,

* Immediately beyond the farm-house the railway gains the summit of terrace *c*, and the view shown in sketch 1 is seen looking up the valley.

some distance below the bridge of Dalreoch, where the three levels are present, the second especially being well exposed.* They may be seen also distinctly at Forgandenny, from the railway crossing, looking across towards Boatmill. But all through these lower portions of the river course the higher and middle terraces show a tendency to coalesce, forming, with the present meadows, only



Sketch 8.—Near Dunning.

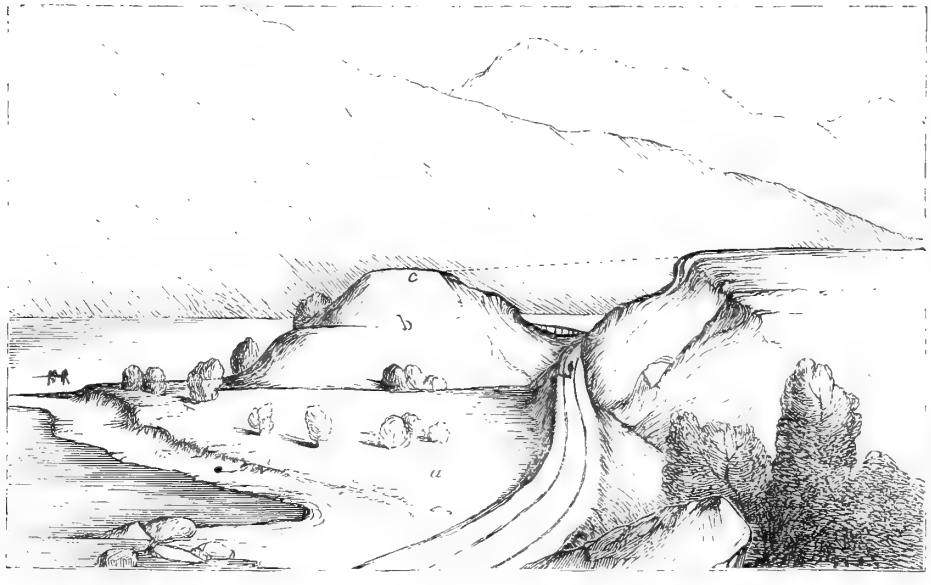
two levels. It was the higher of these which first attracted my attention at Bridge of Earn. By comparing the map with the series of views, the reader will have some idea of how continuously these terraces pervade the whole course of the river valley of Strathearn from the mountains to the sea.

Sketch 9.—Loch Lubnaig, looking up.

Turning now to the river Teith, we have first to notice the shore deposits of Loch Lubnaig, along the western side of which they may be seen running

* The highest terrace *c* is made too prominent in the sketch.

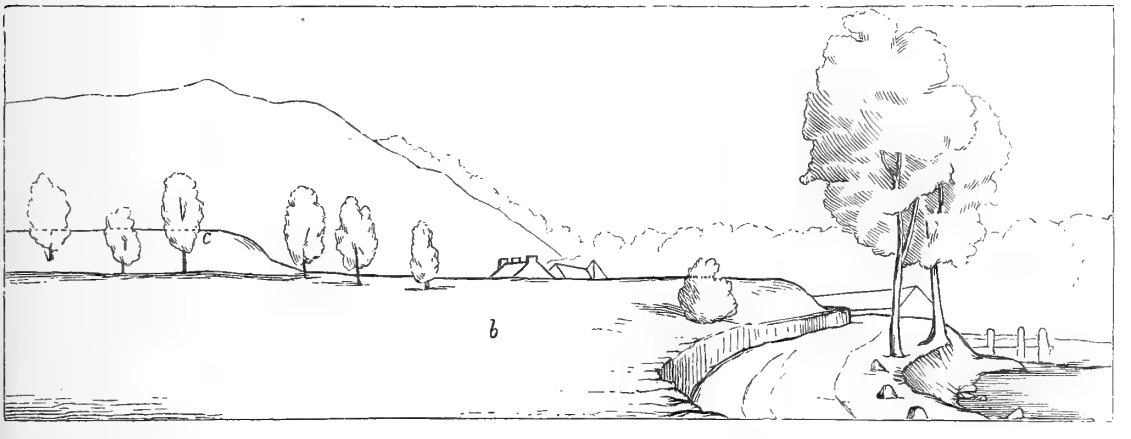
under the shadow of Ben Ledi. First, there is the present shore of the lake, above which rises the second terrace to the height of nearly fourteen feet, and this in its turn is surmounted by the third, about thirty-seven feet over the water. Their position is well given in sketch 9. The point seen in the distance is perhaps the spot where the highest terrace is best displayed, and is given more fully from the upper side in sketch 10. When I first saw it in 1867 its form was that of the dotted line, a shelf projecting and running at its own level along the mountain side. Now it has been cut up by the railway, which has been carried for a considerable distance through these terraces, showing many remarkable examples of drifted gravels and stratified sands, with, in some instances, underlying boulder-clay.



Sketch 10.—Loch Lubnaig, looking down.

These deposits on Loch Lubnaig would seem to point to a time when the waters of the lake stood permanently higher than now. One of our best geologists, Mr Milne Home, has advocated this view, placing the barrier which held back the waters, at the pass of Leny; and it would have been difficult to resist this opinion, but for the circumstance that when we get below the pass we find the same terraces quietly falling into their places, and resuming their course as before. Sketch 11 shows their form when they leave the narrow portion of the valley, going off towards Callander on the left bank—a similar appearance being presented as they sweep round towards Loch Vennachar on the right. The height of the terrace levels is almost identically the same with those on the shores of Loch Lubnaig, and there is the closest resemblance in their inter-

nal structure. If it be said that these in sketch 11 are the margins of a lower lake, there is, first, the difficulty of accounting for their being so exactly the same height above the water, and then there is the fact of their continuity down past all supposed barriers at Gart or elsewhere. Leaving the pass of Leny, and going on towards Callander, we find it is for the most part on these terrace levels that the new west end villas are built; and when the railway was being cut in 1867, it was striking to observe the close resemblance which the fine grey sands, with their false beddings, and the coarse gravels, bore, both in their structure and relative positions, to those seen in the sections on Loch Lubnaig.*



Sketch 11.—Looking from below the Pass of Leny towards Callander.

Further to the east it would be easy to give from different points of the river course examples of the threefold levels; but it may be interesting to take one from its great feeder, the Keltie, so well known as forming the Falls of Bracklin. It is seen (sketch 12) a little above its junction with the Teith, and the view will serve to show that the same system found on the main stream pervades also the tributaries. The upper level presents itself in two stages, and to this fact we shall afterwards refer.

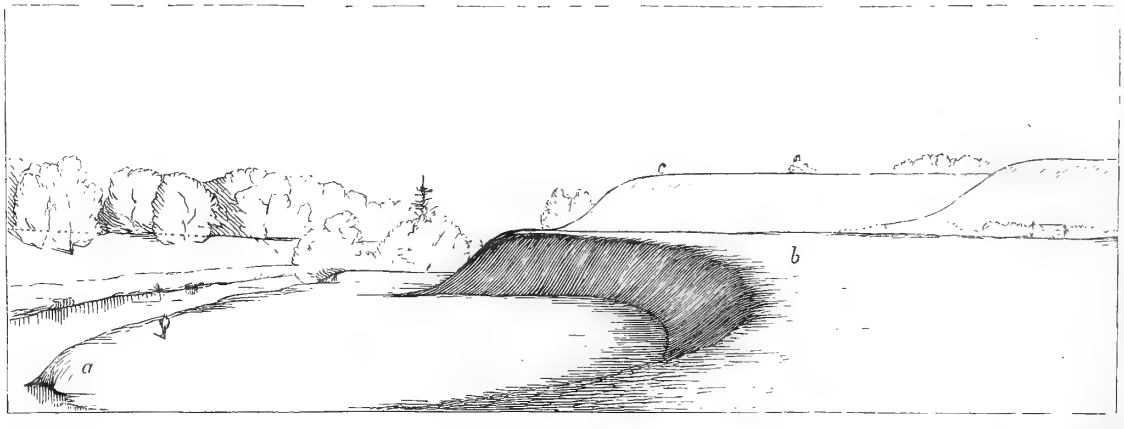
The succeeding portion of the Teith, down as far as Doune, shows a continual succession of the same deposits. The village of Dalvaich especially lies in the midst of a series of these terraces, deserving a far more careful examination than it was in my power to give them. They may be followed down through the grounds of Lanrick Castle, and come out well at the fine old churchyard of Kilmadock. But one of the most striking examples either on the Earn or Teith is that given in sketch 13, above Deanston, on the opposite

* To illustrate this, two sections are given in Plate IV. Fig. 2 is from the terrace on the shores of Loch Lubnaig; fig. 3 is from the railway cutting at Callander. In both the fine grey laminated sands, with their false beddings, are seen to have been denuded in a remarkable way, and are overlaid by coarse gravels.

side of the river, near the farm-house of Clarkton. The highest terrace there shown passes on to the railway station, and has a great part of the town of Doune built on it. It is the same also which may be traced across the river into the grounds of Blair-Drummond, where, in the view immediately opposite

Sketch 12.—On the Keltie, near Cambusmore.

Doune Castle, the three levels are distinctly seen; and here a point is reached of great importance in regard to these terraces. The Carse of Stirling, lying



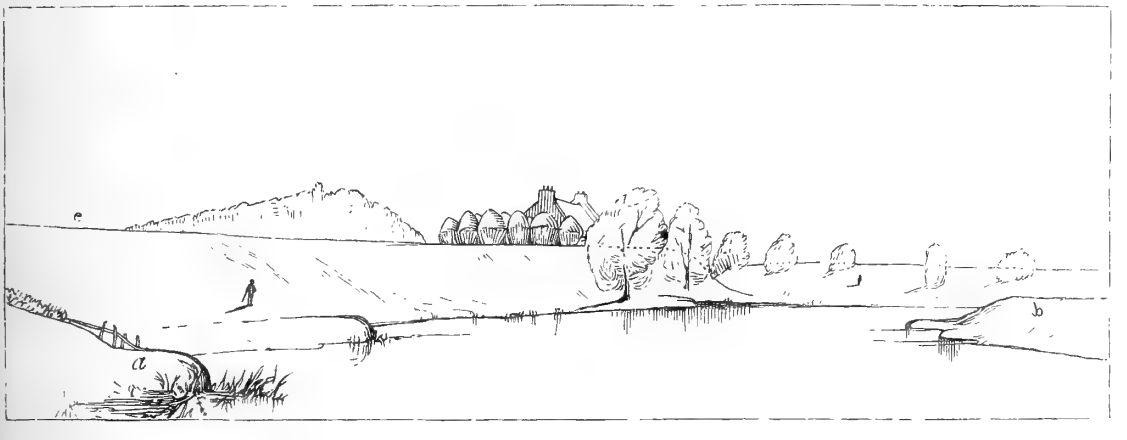
Sketch 13.—On the Teith above Deanston.

between the Forth and Teith, begins to spread out its flat level, and the highest terrace gradually descends and coalesces with the second, just what we saw take place on the Earn, when approaching the Carse lands in the neighbourhood of the sea; and yet all the way some traces of the threefold system may here and there be found. Even at Kildean, near Stirling, and well within tide

mark, this is shown. The highest bank *c* is only twenty-four feet above the river, while the lowest *a* is six; but the opposite side shows an intermediate level *b* of some twelve or fourteen feet. The whole are thus on a very inferior scale. Perhaps it may be thought that this diminution is due to the greater width of the valley. But a still stronger reason, I believe, is the comparative weakness of the current arising from the lower gradient of the incline along these portions of the river course. To this I shall again refer.

The details thus given make it plain that we cannot have recourse to the lake theory, for the terraces are not horizontal, but slope with the valley, and in the case of both rivers we reach a point below which any barrage is inconceivable, and yet these deposits hold on their course.

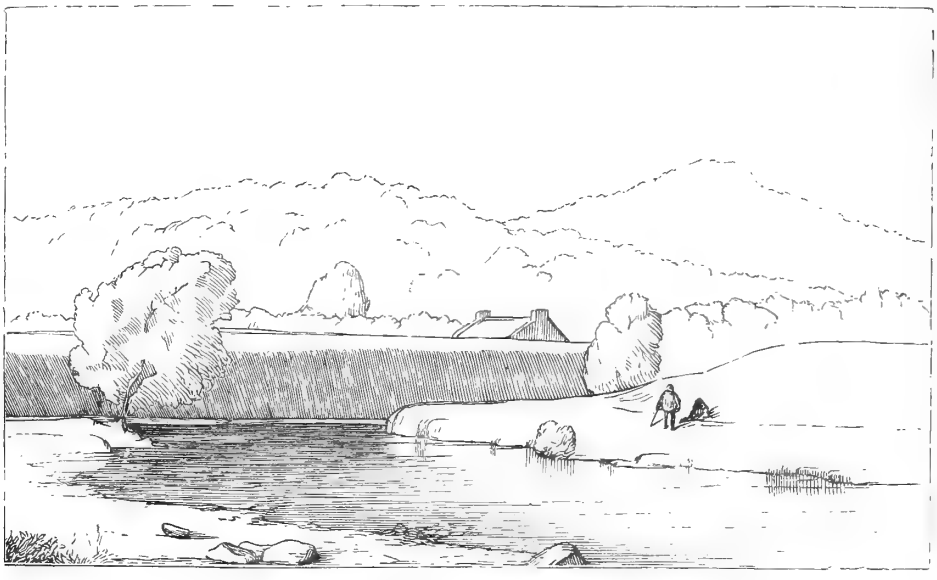
But there are certain additional circumstances to which I ask attention, and which I was led to notice only as the result of having continuously examined the whole course of these rivers.



Sketch 14.—Kildean on the Forth.

First, there is the difference between the upper Earn and its feeder, the Ruchil. There are three streams which meet at Comrie, where the Earn, coming straight from its loch, is joined by the Lednoch from the north, and the Ruchil from Glenartney in the south. Both these feeders show the terraces, those on the Ruchil being, as we have seen, specially remarkable. On searching for them along the upper Earn I was struck by the difference. The present banks of the stream are unusually low, and above these there is a second terrace, some 12 or 14 feet over the river; and this was all I could make out. Some banks which I took for the highest terrace I found were due to the rock structure of the country, and some gravel deposits near Aberuchil belonged evidently not to the Earn, but to a mountain stream which comes from the south. The general appearance of these low terraces along this part of the river will be seen from sketch 15, which the reader is requested to compare with sketch 2, when the difference of scale will be obvious. The threefold

terrace system of the Ruchil is feebly represented by the 12 or 14 feet banks which are continued along the Earn, past Dunira, and on to the loch. In seeking the explanation of this difference a remarkable circumstance was brought out. The floods which come down the Earn at the present day are quite feeble compared with those of its tributaries. The Ruchil is remarkable for the suddenness and strength of its floods, while the flow of the Earn is quiet and equable. Now, the height of the *old* terraces on the two streams exactly corresponds with this. The coincidence is striking, and can have only one meaning. Along the stream, where the floods are still powerful, the old terraces are powerfully developed. Along the stream, where the floods are feeble, the old terraces are feebly developed. The only possible conclusion is,



Sketch 15.—On the Upper Earn.

that it was by the floods of these rivers that the old terraces were really built up in a former age, and that their flooding power was then in proportion to what it is at present.

A second circumstance of the same kind is seen when we compare Loch Earn with Loch Lubnaig. Along the shores of the latter, as we have already shown, there are well marked terraces, and on Loch Earn also a similar deposit is present, but in far less proportions, spreading out especially towards the bottom of the lake, where in September 1869 I found it 12 to 14 feet above the water. This is a weak representative of the 37 feet terrace of Loch Lubnaig. But the remarkable thing is that it almost exactly corresponds to the proportionate rise and fall of the water in the two lochs at present, as caused by a flood on the one hand, and a drought on the other. Both lakes, I was told, were at the lowest ebb at which they had been seen for years. In the case of Loch Earn,

the water was between 3 and 4 feet below the highest water-mark that could be found; while on Loch Lubnaig the difference was about 8 feet. How much of this was due to the absolute depth of the water, and how much to the action of the wind, I could not, of course, say. It was the western shore of the loch in both cases where I took the measurements. But the striking thing is to observe the closeness with which the results correspond with the proportions of the old terraces. In the loch, where the floods and winds of the present day raise the waters 3 to 4 feet, you have the old terrace about 14 feet high. In the loch, where the waters at present are raised some 8 feet, you have the old terrace lying 37 feet high. It is hardly possible to resist the inference that these old terraces are due simply to the greater flooding power of some former epoch.

A third fact which came out was, that these old terraces vary in height just as the present banks of the stream vary at different parts of the river course, and in something like the same proportions. Usually the present banks and haughs of the Earn are 5 to 6 feet above the stream, but in some places we find them only 3, and in other cases they rise to about 10, as near the Bridge of Strowan. The difference is due to the form of the valley, and still more, I believe, to the force of the current. Now, there is precisely the same kind of variation in the levels of the old terraces. As the present banks and haughs may be anything from 3 to 10 feet, so the second terrace varies from 16 to 24, and the highest from 35 to 60. The cases where extremes occur are rare; but this general truth must be recognised, that as the present banks vary in height with the locality, so do the ancient terraces.

Connected with this, however, there is one further circumstance which deserves to be noted; the height of the old terraces varies with the incline of the river bed. Where the incline is greatest, there, of course, the current ran strongest, and there the terraces are highest. When the gradient is low, the terraces get low. It is difficult, indeed, to bring out the exact truth on this point, for it is necessary to make allowance for the varying width of the valley; but in comparing the different parts of the river, there is seen to be a distinct proportion between the steepness of the incline and the height of the deposits. Thus, from the foot of Glenartney to Kinkell, the distance in a straight line is about ten miles, and there the descent of the river is nearly 200 feet. From Kinkell to Bridge of Earn is more than eleven miles, and there the descent is about fifty feet. Now, it is along all the upper section, where the current ran strong, that the terraces rise high; and along all the lower portion, where the current ran slow, the terraces subside. Precisely the same thing is seen on the Teith. Above Doune the descent is rapid, and the current strong. Below Doune all is flat, and the current gets slow, and it is in the upper portion that the terraces are raised high, while below Doune their height markedly diminishes.

Here, again, the facts point to these river currents as the agent which built up the terraces. In estimating the facts, however, care must be taken to include some considerable length of the river course. A short reach, where the water runs level and slow in the midst of rapids, may be the very place where the deposits most accumulate. But take any considerable distance, and it will be found that in proportion as the gradient is steep* these old terraces rise in height, and as the gradient gets low the terraces diminish.

If we could only suppose a time when the river had the power of rising in flood to the requisite height, the whole phenomena would admit of the most easy and natural explanation. The simple key to the whole would be the principle, *that just as the river deals now with its present channel and present banks, so it dealt in the old time with those high lying terraces.*†

Putting together then the whole of these facts, we can now see what this threefold system of terraces means. It is simply a record of the different levels at which the most powerful river floods stood at different periods of the past. The highest of these lines of deposit is evidently the oldest, a gravelly and sandy terrace which runs along our valleys at a height of from 35 to 60 feet. Then we find a descending scale as the floods grew less and less powerful, subsiding towards the present state of things. Rather more than half way down the scale there is an intermediate terrace about 16 to 24 feet above the river, and forming an outstanding feature of these deposits. It seems to indicate that when the descending waters reached that stage a pause of considerable duration took place, during which the action of the highest floods went on at that level. Subsequently there was a descent from the middle terrace to the present banks. Between each of the stages indeed, there are intermediate lines of deposit occurring here and there in different localities, and putting them all together it would be possible to construct a whole series of graduations by which the highest terrace would be found to descend to the second, and the second to the lowest. Still there can be no doubt that the three terraces form the prominent feature of these deposits.

The general result thus seems to be, that along the sides of these river valleys, we read the history of various ages during which the floods gradually ran at a lower and lower level, and in that record there are three great lines which stand out from the rest as indicating each some considerable period during which the waters remained stationary, till at last the intervals were all passed over and the present state of things was reached.

* This does not apply when one follows the stream up among the mountains, where for the most part the terraces are absent. Is it that denudation has swept them wholly away? or is it that during the epoch of these old floods there were glaciers still lingering in the upper portions of the river-valleys?

† More than twenty years ago, Mr Milne-Home described the terraces above Perth as haughs or river flats, but he seems to connect their formation with the bursting of lakes. See "Trans. Roy. Soc. Ed.," vol. xvi. p. 418. I do not refer to other districts.

Their Geological Position and Age.

In regard to the time when these terraces were formed it is difficult to pronounce with confidence, but there are certain indications which deserve attention.

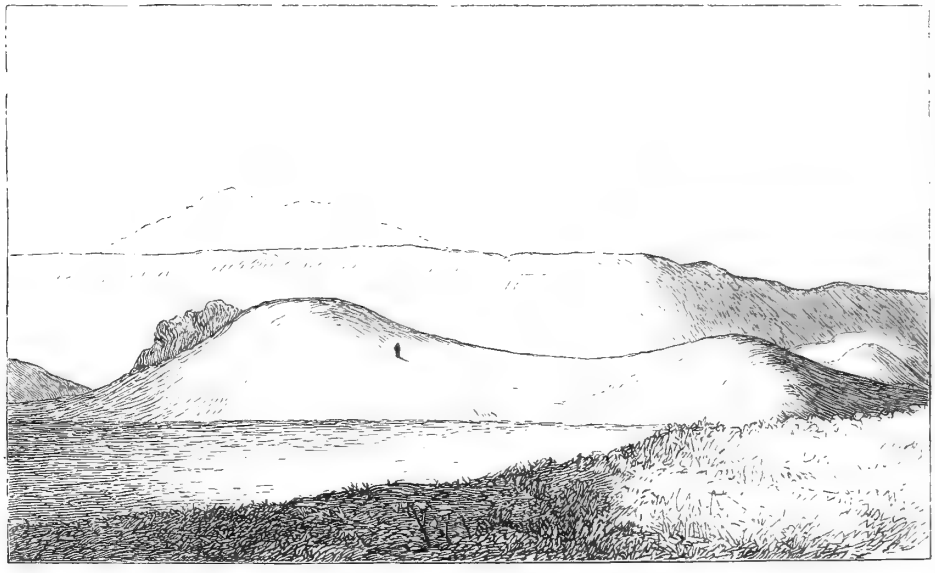
Near Comrie we find some antiquarian remains which go a good way back into the past. The site of the Roman Camp is close to the village, and a little further to the east there is what the Government Surveyors have laid down as a small roundel or Druidical structure, a circle raised above the surrounding ground, in the middle of which there once stood a rude and apparently unsculptured monolith, now prostrate. These Roman and Druidical remains are all on the expanse of the second terrace formerly referred to. So far back then as they carry us the intermediate terrace had been already formed.

Leaving archæology and appealing to the methods of the geologist, it is clear that these deposits have been laid down subsequently to the glacial epoch in Scotland, for no glacier can have touched the valleys since the terraces were deposited. We have traced them on Loch Lubnaig up to a height of 400 feet above the sea, and their state of preservation makes it plain that up to that level at least no glacier nor icecake has since their formation grazed hill or valley.

It is equally plain, and for the same reason, that the sea had finally retreated from the land. Some minor change of level there may have been about the Carse of Stirling, but already the sea must have finally left the valleys free for the action of the river floods.

There seems indeed to be good ground for believing that a series of peculiar deposits is interposed between the oldest of these terraces and the glacial epoch. In working back, and trying to make out stratigraphically the place of the highest terrace, we are in contact with a set of gravels, &c., which in the present state of our knowledge are particularly obscure. I refer to a series of mounds or hillocks sometimes round or sinuous, sometimes drawn out as long lines in the form of escars or kames, but invariably when laid open showing that they have been deposited by water in a state of disturbance. Occasionally they come down into the valleys, but for the most part they stretch away out over the higher grounds. Examples are to be seen along the course of the Earn, but they are still more striking on the Teith, and especially near the village of Dalvaich. In sketch 12 it will be observed that the highest terrace *c* is shown in two stages. Following the oldest and highest of these stages it appears to connect itself with the deposits in question, which, a little to the west of Dalvaich and north of the turnpike road, begin to spread out and go far up over the face of the country. One of these lines of kames is given in sketch 16 showing another and higher ridge of the same kind behind it. The end

view of the first of these lines is seen in sketch 17, showing the form which these deposits assume. The question as to how they were formed is one of the



Sketch 16.—Kames west of Dalvaich.

most difficult in geology. That they are not due properly to the action of flooded rivers is plain, for they may be traced up and out over the level face of the country, and are nowhere more fully developed than towards the water-

Sketch 17.—Kames west of Dalvaich.

shed between the basins of the Forth and Tay, where the action of streams must have been feeblest. It would be natural to suppose that they were

submarine banks belonging to the time when Scotland was submerged, but this seems disproved by the fact, that wherever such submarine banks occur, they swarm with all kinds of marine life, while in regard to any trace of such life, these kames are invariably an utter blank. But, indeed, similar difficulties attend all the theories hitherto suggested. Nor ought this to surprise us. We do not know what it is for a country once incased in ice as Greenland now is, to have the ice-sheet lifted off or melted from the face of hill and plain. Into what forms the subjacent materials of gravel and sand would be thrown—what would be the modes of operation of the forces let loose, it is difficult to conjecture. No example of such a process has been witnessed, and yet it is certain that Scotland passed through it. It is little wonder if among its results there should be some residual phenomena for which it is difficult to account. Among these it would seem we must place the kames or escars, and the gravel mounds associated with them. At all events, their position appears to lie between the period of arctic climate and the time of that series of terraces which this paper describes, and which were, it is probable, built up out of the materials furnished by these pre-existing gravel deposits.

In deciding the geological position of the terraces, however, we must not forget the fossils of the peat and the associated carse clays referred to at the beginning of this paper. For several miles above Bridge of Earn these remains occur in abundance, but evidently they have been drifted from some distance, brought down by the current, and they show what the flora of Stathearn had been at the time when the peat and carse clay were deposited. In regard to the extension of the carse clay itself, it can be traced up as far as Kinkell, where its grey colour and fine unlaminated structure were quite distinct,* forming part of terrace *c*, as shown in sketch 7. Above Kinkell, the same terrace runs on, but the place of the clay is taken to a great extent by sands and gravels, and these materials get on the whole coarser the further you go up the stream. All this is easily explained. The coarser the material, the less easily is it moved forward by the current, while clay in the form of mud is floated to the furthest distance. The highest terrace, therefore, which consists at first of gravel and sand, with a little clay, presents through all the lower reaches of the river little else than large sections of the finest carse clay. These carse clays, and the underlying peat near Bridge of Earn, form, as we have seen, properly only one deposit, and the result would seem to be that these fossil leaves and hazel nuts, &c., give us the flora which grew along the valley at the time when the oldest of these terraces were formed.†

* See Fig 1, Pl. iv.

† There seems good ground for holding that the peat beds of the Earn belong to the time when the land stood comparatively high. But when Mr Jamieson makes the land again sink, and brings in the sea in order to deposit the estuarine mud of the carse, not only does the fossil evidence go against this, but there is the decisive fact already pointed out, that the peat and the carse clay are so

If this be so, it would appear that the glacial epoch must, to a great extent at least, have passed away. Its close had been marked by the formation of the kames, those ridges of gravel whose strange forms meet us on our uplands and over the face of the country. Then there came a more genial time, shown by the large size of the hazel nuts, when the present Flora was established. And then it was that those vast floods seem to have flowed forth, which filled our valleys, and left their record in these highest terraces. What was done during the Moray floods may have been done of old on a still greater scale, and these high-lying deposits may be the proof of it.

Antiquity of Man.

The views thus far stated must be judged of on their own merits, apart from any question as to the antiquity of man. The advocates of extreme opinions on this subject have relied to a great extent on geological evidence, and some of their strongest arguments have been derived from the flint implements of the Somme in France, and the Brixham Cave in Devonshire. It is held that wrought weapons, the work of man, are found along with the remains of extinct mammalia, and occur in such a way as to show that man had been their co-temporary. If this were all, however, the argument would have little force, for the inference would be perfectly open, either that the human period must be carried further back, or that the time of these extinct mammalia must be brought further down. Were we mistaken as to the duration of man—must it be carried much further back among these extinct animals? or were we mistaken about these extinct animals—do they come down into the human period? Men would lean to one or other alternative according to their pre-possessions. Other circumstances had therefore to be appealed to, and, in fact, the stress of the argument has come to rest on the position of the deposits in which these remains occur. Those on the Somme were examined by one of our best observers, Mr Prestwich, who reports that the oldest beds containing these fossils lie along the valley, at the height of about 80 feet above the river course. The time when these were deposited was the time when man and the mammoth lived together. Since then the river has worn down the valley, cutting through rock, &c. some 80 feet, and the human period must be carried back through the ages which can rationally be supposed needful for this operation. He refuses to admit "hundreds of thousands of years," but if his view be taken, the period must be very long. The argument in the case of the Brixham cave is similar. The remains of human art and of these extinct animals are found together in a deposit which must have been carried by running water into its present position. But the entrance to the cave is in the

associated as to form properly one deposit. At whatever time the one was formed, the other was also. The conclusion to which all the evidence seems to point is, that the whole system of these river terraces was formed at the time when the land was elevated above its present level.

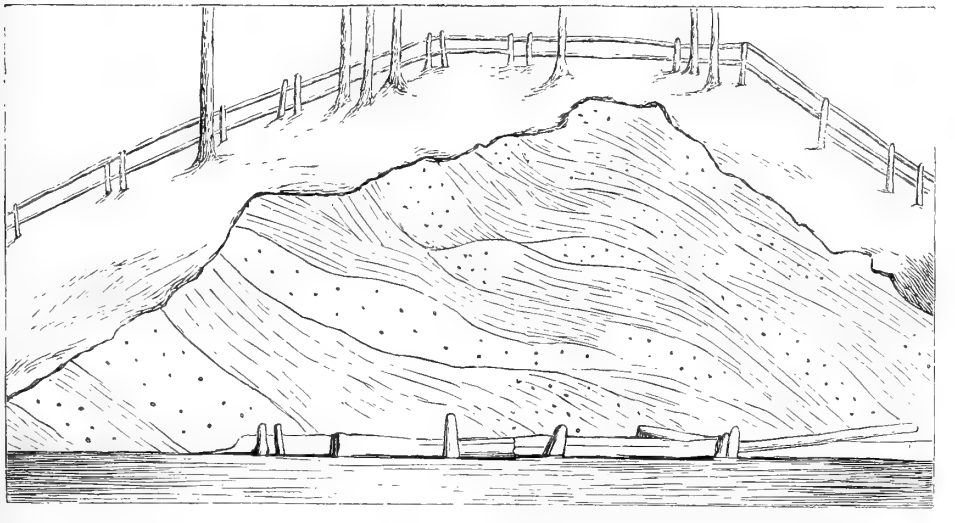
side of a valley 60 feet above the present bed of the stream, and we are told that the human period must be carried back through the long ages needful for wearing down the rocky floor of the valley. These are, I believe, among the strongest arguments from geology.

But now, if the analogy of our Scottish rivers may be trusted, there seems fair ground for asking whether such arguments have not been carried too far.

1. First, it is plain that previously to the time when these high-level terraces were deposited along our river courses, the rocky structure of our Scottish valleys had been hollowed out as deep as they are now. In proof of this, it is enough to refer to the fact that the boulder-clay which belongs to an antecedent period is found occasionally forming the floor of the valley over which the streams flow.* If, then, the formation of the valleys of France and Devonshire were analogous to ours in Scotland, their rocky structure was excavated not after, but before, the deposition of the high-level gravels.

2. Secondly, The floods which piled up these old high-level deposits seem to have had the power of doing so at a time when the river-bed was cleared of all other materials, and stood at as low a level as the present streams.

This might be shown by various examples along the Earn; but we take a



Sketch 18.—Below the Castle of Monzie, 1866.

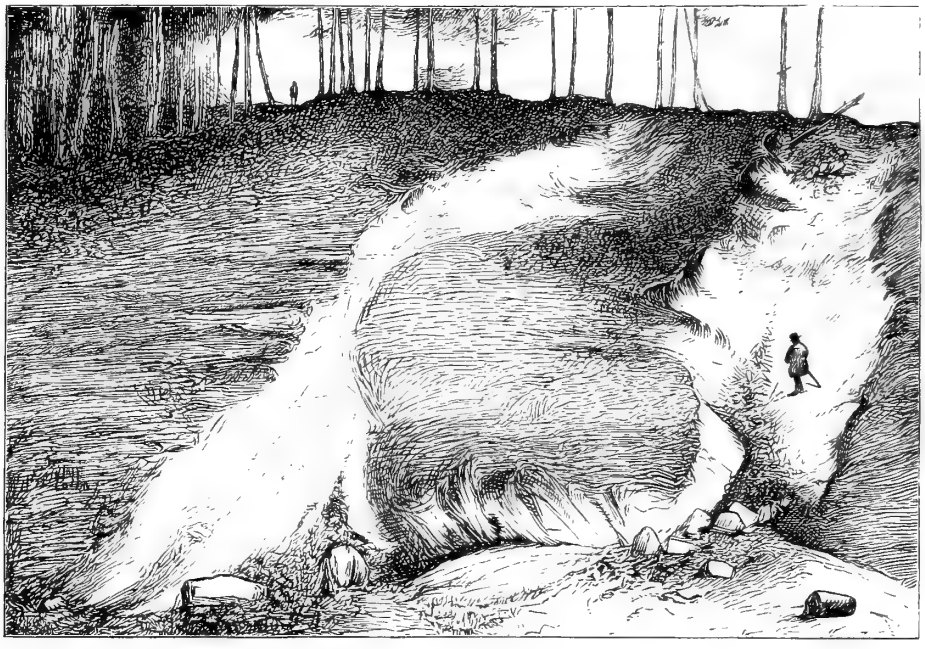
single case from the valley of Monzie. Sketch 18 shows a spot where the stream has cut into the highest terrace,† laying it open from the base up to a height of 50 feet, and showing that it is composed of stratified gravels, sands,

* Seen in the valley of the Turrit, for example, above Crieff, and also in that of Monzie, in both of which it underlies the high-level gravels. My attention has been called to the fact that this view had been brought forward in the Memoirs of the Government Survey on Berwickshire, p. 50. 1863.

† This forms a continuation of terrace *c* shown in Sketch 4 on the left bank of the stream. It lies a short way further up the valley.

&c., the work of running water flowing down the valley. Eighty yards further up, the same bank (sketch 19) is laid open up to its whole height of 120 feet, where, in one of the gullies, innumerable alterations of the same strata are shown. The last 20 feet* at the top are particularly well seen, as also are the 50 feet at the base in Sketch 18.

Now that this terrace was formed by river floods is shown by its connection with similar deposits further down the stream. Those seen in Sketch 1 must



Sketch 19.—Below the Castle of Monzie.

have been a river formation from the slope of their surface down the stream, and not only is their structure identical with that at Monzie, but—allowing for the effects of partial denudation—they may be traced running on till the one series actually meets and passes into the other, forming two stages of terrace *c*, as in Sketch 12.

But if these deposits were formed by river floods, a single glance at such a section as that in Sketch 18 will satisfy every geologist that the running water began its work at the bottom, down on the level of the present river bed. When the first stratum was laid down, the running water had found the valley cleared out down as low as it is now. Explain that matter how we may, these old floods must have had the power of doing this; beginning at the level where the stream runs now, they could form a terrace, piling stratum above stratum, up to the height of 120 feet, as far, indeed as the water was able to rise.

It is plain, therefore, that if the analogy of our Scottish rivers will apply to

* See Plate iv. fig. 4, showing the arrangement of the gravels and sands forming the upper portion of the terrace.

those of France and England, the long period required for the supposed lowering of the river-bed is got rid of. If the stream which flows through the valley at Brixham could do what has been done by the burn in the valley of Monzie; or if the Somme could do what the Teith has done along its course, any amount of high-level gravels might have been piled up, or carried into caves after the valleys had been hollowed out, and the bed of the stream brought down to where it now is.

But are we right in supposing that the analogy of our Scottish rivers will apply to those of England and France? The presumption certainly is that their formation was analogous.* But we have more than mere presumption. Mr Tyler, an English geologist, has been investigating the case of the Somme, and finds evidence of a pluvial period—a time of high floods sufficient to account for the high-level gravels. The body of facts which he has brought together deserve careful consideration, and it will certainly be matter of deep interest if the deposits of the Somme are found to record the same story which we have been reading along the Earn and Teith.†

I have no wish to push this argument beyond what is perfectly fair. These terrace-like deposits form a subject which has been too little investigated. It may turn out that they reveal to us a period of river floods much greater in volume than men are generally prepared as yet to admit. And it may also be that those inferences which have been drawn as to the duration of the human period may be very seriously affected. It would surely be safe to have more complete examination before judgment is given. These deposits belong to what in geology is a very recent period indeed, and all I would ask is that the facts be more fully investigated, lest in arguing for extreme views as to the antiquity of the race men be found importing fallacious elements into the calculation.

But how shall we account for the volume of water necessary to produce such floods? Looking to the width of some of our valleys, and to the height of these deposits, is it not difficult to believe in the existence of such torrents? In dealing with this question care must be taken not to exaggerate the diffi-

* An attempt has been made to deny this on the ground that Scotland was submerged during the glacial epoch, while Picardy and Devonshire were not—the object being to show that the French valleys were excavated at a later period than the Scottish. But this argument can hardly be urged by those who hold that the formation of valleys is due mainly to subaerial forces and hardly at all to marine action. If the difference between the two countries be that France not having been submerged was continuously acted on by these eroding agencies, while Scotland was withdrawn from them by being buried beneath the sea, how will that prove the French valleys to be of later formation than the Scottish? So far as that difference goes it should surely prove the reverse.

† "On the Amiens Gravel," by Alford Tyler, Esq., F.G.S., "Journal Geol. Soc. Lond." vol. xxiv. p. 103. In one respect Mr Tyler's reading is different. He regards the lower terrace, the loess, as the bank of the ancient river when in its ordinary state, and the higher terrace as its bank when in flood—referring both to the same period. This differs materially from the view which I have been led to take, namely, that each terrace is the highest flood-mark of its own time, just as the present banks and haughs are related to the floods of the present time.

culty. Our rivers, as we see them at present, flow along a comparatively narrow channel, the greater part of the river valley being usually occupied by level meadows. When a flood comes, it is only the narrow channel that needs to be filled; and then, should the water rise but a very little over the brim, it will spread out like a sea on either hand. But, after all, it is the banks and meadows which fill the space of the valley. Except in the central channel the sheet of water may be comparatively shallow. And so in that old time the river would have only its central channel lined by banks proportionally higher. The flood would be needed to fill the river bed, flowing perhaps over the brim and out over the surface. In this way these old terraces would be formed just as the present meadows are. The volume of water needed was by no means what would have been required to fill the valley if it had been empty. It would be enough if the confined river bed were filled to overflow.

But, if things were on such a scale that the river channel was lined with banks 50 or 60 feet in height, where was the water to come from which could rise to such a height? One explanation has been sought for in the melting of the ice and snow as the glacial epoch passed away. At present, when the ice and snow melt in northern latitudes, the arctic rivers rise annually from 40 to 50 feet. This of itself would go a long way to solve the problem. Besides, there was more than the annual melting which takes place at present under ordinary conditions. The fact that the glacial epoch was passing away, must be taken into account. If these terraces may be taken as a record of the time when the great icy covering was melting off the face of the land, and Scotland was passing from the rigour of an arctic climate to its present condition, the currents which filled our valleys may have been increased to an extent which it is difficult to estimate. Swollen lake and flooded river may have risen to a height sufficient to meet all the conditions of the problem we are considering.

Another explanation which has been suggested, is the existence of a period of great rain-fall—a "pluvial epoch," as it has been named by Mr Tyler. This may have arisen either from the quantity of rain having been increased, or from the rain-fall having been concentrated—a greater amount falling in a given time. Some idea of these floods of the old time may be got from the account of the Moray floods, as given so admirably by Sir Thomas Dick Lauder. They occurred in 1829, and were owing to a fall of rain to the amount of $3\frac{3}{4}$ inches having taken place in twenty-four hours. In regard to the height to which, on that occasion the water rose, the writer mentions having himself seen a man wade into the water and capture a salmon on the haughs 50 feet above the usual level of the Findhorn, pursuing the fish with his umbrella and driving it ashore. The violence and velocity of the currents he describes in striking terms. "It was scarcely possible to follow with the eye the trees and wreck which floated on its surface. The force was as much more than

that of a raging ocean as gunpowder ignited within the confined tube of a cannon is more terribly powerful than the same material when suffered to explode on the open ground."* It is no wonder if, with such force at work, there should be strange tales to tell of the results of denudation. Instances of farms, where six, eight, or ten acres were eroded and swept away, are so common as hardly to deserve notice. At Mains of Orton, on the Spey, when the proprietor, Mr Wharton Duff, came, after the flood, to examine his farm, he found he must make a new bargain with the tenant, and deduct some 50 or 60 acres which were gone. At Braemoray, the whole low land was annihilated, and the green slopes of the hill converted into naked precipices. At Relugas, the pleasure-ground and lawn were swallowed up, and in their place that river might be seen raging for 300 yards along the brink of a red alluvial precipice 50 feet high. At Dalrachney, the river Aven attacked a wooded bank from which it carried off a mass of not less than 90,000 cubic yards, leaving a sandy precipice 90 feet high. At Tillyglens, on the Dorbach part of the farm, an acre in extent was carried off bodily before the eyes of the farmer; and, as he looked at it sailing away, he observed another half acre detach itself from the hillside and descend some 60 feet into the valley, carrying a grove of trees on its surface.

But if the flood could thus tear down, in the same proportion it could build up, often leaving its deposits where they were little welcome. On one of the farms of Captain Macdonald of Coulnakyle, consisting of 200 acres, 150 were ruined by a deposit of sand and gravel to the depth of 3 feet. At the mansion house of Ballindalloch, the garden was covered by sand to such an extent that only the tops of the apple trees were seen rising through it, presenting a strange appearance still laden with fruit. Yet more remarkable was the height of the deposits at the Mill of Logie, near Relugas. The flood completely filled with sand the lower story of the mill rising 28½ feet above the ordinary level of the river. These examples are instructive; but, in order to appreciate the subject, the whole volume should be studied, showing the marvellous power of such torrents, both in denuding and in building up. If we suppose, that from whatever cause,† there had occurred in the old times a series of torrents, surpassing the Moray floods as these latter surpassed the ordinary summer floods of

* Page 101.

† It has been suggested by Mr Buchan of the Scottish Meteorological Society, that if the bed of the sea round our coast were elevated, and especially in the direction of Greenland the effect on the climate would be greatly to increase the river floods. Now already, on stratigraphical grounds, we have been led to the conclusion that it was precisely at that period of elevation that our high river terraces were formed. (See note, page 169.) The coincidence is remarkable. The whole stratigraphical evidence makes it probable that these high gravels were deposited just at the time when meteorology teaches us to expect that the river floods would be much beyond the present; and if even in the present state of things there could be such results as the Moray floods have to show, we may be prepared for the still more striking effects of that former age.

our rivers, nothing could be easier than to explain the whole phenomena of these terraces with their high-level gravels.

There need be little difficulty as to where the materials would be found which were to form the great masses of these sandy and gravelly deposits. The escars and the associated mounds sufficiently show what immense accumulations of such materials had been provided under the action of ice, and perhaps of the under-ice rivers of the glacial period. If exposed to the action of torrents on a somewhat greater scale than those of the Moray floods, such materials would soon be disposed of. No great lapse of time need to be supposed. If the whole of the above results in Morayshire were produced in about twenty-four hours, it would be difficult to say what might not be done by a single century of such inundations.

Note.—In this paper attention has been called to the absence of marine fossils from the terraces at Bridge of Earn and elsewhere. If such fossils should occur, it would be important to inquire whether they belonged to the time when the terraces were formed. Sometimes portions of antecedent deposits are overlaid or enclosed by the materials of the terraces—portions of rock *in situ*, for example, or of boulder clay. In the same way there might be found portions of those marine shell clays which belong to a previous period.

IX.—*On Spectra formed by the passage of Polarised Light through Double Refracting Crystals.* By Francis Deas, M.A., LL.B., F.R.S.E.

(Read, 6th June 1870.)

It is familiarly known as one of the commonest experiments in optics that when a beam of polarised light is passed through a thin film of mica or selenite, and subsequently analysed either by reflection or by double refraction, two colours are seen complementary to one another, and alternating with one another at each 90° of a revolution of the analysing plate or prism.

It might be expected that the coloured light thus obtained would, if thrown into the form of a spectrum by means of dispersion prisms, exhibit some peculiarities, and such is the case as will be seen from the following experiments :—

To make the experiments intelligible, it may be well in the first place to say a few words about the instrument employed, and the method of using it.

Any spectrum microscope ought to answer the purpose provided that in addition to the spectroscopic arrangement a pair of Nicol's prisms can be attached, one below the stage and the other over the eye piece. Both should be capable of being rotated, and it tends much to facility of working as well as to exactness of result that both the polarising and the analysing prism should carry graduated heads, so that their axes may readily be turned to any required degree of inclination to one another.

The instrument I employed was a large Smith and Beck. The spectroscopic arrangement consists of an adjustable slit attached to the under part of the substage below the achromatic condenser, and a set of direct vision prisms which are inserted in the body of the instrument immediately above the object glass.

By proper focusing, an image of the slit is thus formed by the achromatic condenser in the focus of the object glass, and a fine spectrum obtained filling the whole field.

This arrangement, it will be seen, differs considerably from the spectrum microscope in common use in which the dispersion prisms are placed close to the observer's eye, the slit being in the focus of the eye lens. The former arrangement has this manifest advantage, that owing to the distance of the prisms from the eye, the spectrum fills the whole field ; also, that the apparent breadth of the spectrum can be varied at pleasure by a change of the magnify-

ing power employed. Each form of arrangement has, however, its advantages as well as disadvantages, which it would be out of place to discuss here.*

The polarising part of my apparatus consists of two NICOL'S prisms, for one of which, when desired, a double image prism can be substituted.

The polarising prism is carried on the substage. It is inserted just above the slit in a short tube in which it can be freely turned by a graduated head. The analysing prism is placed in the usual way—in a cap over the eye piece.

The film of selenite to be examined having first been mounted in balsam between two thin glasses is placed on the stage of the microscope like an ordinary object.

It is a great convenience in this class of experiments to have the stage of the microscope not only capable of rotation in the optical axis of the instrument, but graduated.

By this means we can at any time, without displacing the film under examination, adjust its neutral axes at any required angle to the plane of polarisation.

With regard to the mounting of the selenite films for examination the following method will be found convenient :—Make in the turning lathe several wooden disks about two inches diameter and one-eighth of an inch thick. Through the centre of each a hole must then be bored of about half an inch diameter. A small portion round the hole is then scooped out so as to form a cup, and in this the selenite is placed and secured with sealing-wax.

The axes of the selenites are then determined and marked on the rims of the disks.† In this way any two or more selenites can be used in combination with their axes set at any required angle to one another.

It remains only to trace the course of a beam of light in passing through the foregoing combination. First the ray, having been reflected from the mirror, passes through the slit. It is then polarised by the first NICOL'S prism, after which it passes through the lenses of the achromatic condenser, and appears as an image of the slit in the focus of the object glass. Having passed through the selenite and the object glass, the ray enters the dispersion prisms and is drawn out into a spectrum. This is magnified by the eye piece through which the ray, having passed, is lastly analysed by the second NICOL'S prism.

The loss of light from the number of the above media is not so great as might be supposed, still an intense source of light is desirable for satisfactory results. A good artificial light placed close to the mirror will be found the best. In diffused day-light rays are apt to enter the object glass by reflection from the brass work without first passing through the polariser, by which the beauty of the spectrum is impaired.

* A similar form of instrument will be found described in the "Quarterly Journal of Science" for October 1869.

† The graduated rotatory stage above mentioned, and which is supplied by SMITH and BECK, affords a ready means of doing this.

To understand the bearing of the experiments, it is necessary to keep in view the different effects of a doubly refracting film upon polarised light, according to the position of its axes, with respect to the planes of polarisation.

Suppose we take a film of selenite, such as those commonly sold as an adjunct to the polarising microscope, giving, as its two colours, a pinkish red and its complementary green. Such a film will, if examined between two NICOL'S prisms, act on the light according to the following laws :—

1*st.* When a neutral axis of the film is in the plane of primitive polarisation, the film will exercise no influence on the light; if, therefore, the prisms are set with their axes perpendicular the field will remain dark, if the prisms have their axes parallel the field will contain only white light.

2*d.* If the prisms are placed with their axes perpendicular, and the film is made to rotate, there will be four points of darkness at each quarter of a revolution, viz., when an axis of the film is in the plane of polarisation, and between these four points, the same colour (say green) will occur.

3*d.* If the prisms are set with their axes parallel, and the selenite is rotated, the field will be white at the four points where it was previously dark, and of the complementary colour (red) between each of these four points.

4*th.* If the selenite is fixed with its neutral axis inclined 45° to the plane of primitive polarisation, and the analyser made to rotate, the field will be alternately red and green in the four quadrants.

5*th.* The colours are always of maximum brightness when the axes of the prisms are perpendicular or parallel, and the axes of the selenite inclined 45° to the plane of polarisation.

Suppose, now, we repeat the above experiments, using the polarising spectrum microscope above described, and let us call the point in the revolution of the selenite at which either of its axes is in the plane of primitive polarisation, the zero point, from which the number of degrees through which it is turned are measured.

Let the prisms be set with their axes perpendicular to one another, and the selenite rotated on the stage. The spectrum will, of course, vanish at the four zero points. Between these points, however, remarkable phenomena occur. A person unacquainted with the true nature of the colours of polarisation, and proceeding on the analogy of homogeneous light, might expect to get a spectrum consisting only of green rays, seeing that that is the colour of the field when the spectrum arrangement is removed. This, however, is not the case, and the result very beautifully illustrates to the eye what is well known theoretically to be the true nature of these colours. What we obtain is a continuous spectrum consisting of all the prismatic colours, in greater or less intensity, with the striking peculiarity that there is a well-marked dark band in the red, similar in appearance to the well known absorption bands which many substances pro-

duce in the spectrum, only blacker and better defined than these are ever seen.

The following is the mode in which the band makes its appearance. As the zero point is passed, the light first makes its appearance in the green of the spectrum, from which point, as the selenite is rotated, the light opens out in both directions. When the light reaches the red, the black band makes its appearance, and attains a maximum blackness when the selenite is at 45°, viz., when, without the use of the dispersion prisms, the field would contain green light of maximum brightness. When this point of revolution is passed, the band again fades, the spectrum becomes obscured at each end, the darkness creeping in towards the green, till at 90° the spectrum has again vanished. The same phenomena recur at each quarter of a revolution.

Let the Nicol's prisms now be set with their axes parallel, and the same selenite rotated on the stage as before. The result is what we should be led to expect from the last experiment. At the zero points the selenite exercises no influence, and we have a continuous ordinary spectrum. As a zero point is passed, however, a dark band makes its appearance, but this time in the green rays. The band is at first faint and nebulous, but becomes blacker and sharper as the stage is rotated, till at 45° it attains its maximum. The spectrum in this experiment never vanishes, but is apparently quite continuous throughout, save for the appearance of the black band.

Lastly, let the selenite be fixed at 45° from the zero point, and the analyser rotated. We have now a combination of the two previous experiments. The band in the red appears alternately with the band in the green at each quarter revolution, the former being at its maximum when the axes of the prisms are perpendicular, the latter when these axes are parallel.*

The above are the appearances which present themselves in the case of most films of selenite of a medium thickness. In some cases, however, two, or even three, black bands occur simultaneously, these being always followed by as many complementary bands, when the analyser is turned through 90°. The number of bands can generally be multiplied by using two or more films in combination, and the appearances can be still further varied by changing the degree of inclination of the axes of the two films to one another. If the two films are placed with their similar axes coincident, we obtain, of course, the spectrum appropriate to a film equal to the sum of the thicknesses of the two films, while, if dissimilar axes are superposed, the spectrum is that due to the difference of the same. I have two films which, when properly combined, give no less than six well-marked bands simultaneously.

* If the axis of the selenite makes a greater or less angle than 45° with the plane of polarisation, the result is that while the same band still recurs after 180° of a revolution of the analyser, the complementary band is no longer separated from it by 90°, but by a greater or less angle.

But the most striking of the phenomena presented by films which give more than a single band, remains still to be noticed, viz., the motion of the bands along the length of the spectrum. This can generally be easily seen by using two films in combination, and properly adjusting their axes.

The following may be taken as an illustration of this experiment, of which many varieties may be made. Suppose the two films are so adjusted as to give two black bands, one in the orange and one in the blue, which we may call *a* and *b* respectively. On rotating the analyser, each band is seen to divide into two halves. The right hand half of band *a* runs along the spectrum, and unites with the left hand half of band *b*, which advances to meet it, the two coalescing into a single band in the green. At the same time that this has been going on, two entirely new bands have made their appearance. These seem to originate respectively beyond the visible rays at each end of the spectrum, and to advance in opposite directions till they are met respectively by the left hand half of the original band *a* and the right hand half of the original band *b*. The result is, that when the analyser has been turned through 90°, we have a spectrum with three black bands, one in the extreme red, one in the green, and one in the indigo.

Continuing still further to turn the analyser the above phenomena are reversed. Each of the three bands splits into two, moving in the reverse of their former directions, until when 180° is reached the original spectrum with its two bands recurs.

A curious variety of this experiment occurs when a circularly polarising film is interposed between the analyser and the film producing the bands. The nature of the movements of the bands is now entirely changed, the order of motion being all in the same direction, and the bands appearing to chase one another along the length of the spectrum, making their appearance at one end and disappearing at the other. To produce this effect, the "band-producing" film should be set with its neutral axis at 45°, and the circularly polarising film superposed with its neutral axis in the plane of primitive polarisation. If the axis of either film is turned through 90°, the motion of the bands is reversed; *i.e.*, if the bands formerly moved from left to right, they now move from right to left. If the two films are both placed with their axes at 45° to the plane of polarisation, the only effect of the circularly polarising film is to alter the position of all the bands by a corresponding amount (*i.e.*, to increase or diminish their refrangibility) without affecting the nature of their motions.*

A very pleasing and beautiful variety of the foregoing experiments may be obtained by using a double image prism as the analyser instead of the Nicol's

* The effect of circularly polarising the light before it passes through the selenite, is simply that the occurrence of the bands is irrespective of the inclination of the axis of the selenite to the plane of primitive polarisation, and depends solely on the position of the analyser.

prism. Two spectra formed respectively by the ordinary and extraordinary ray are thus obtained, which by rotating the double image prism may be made to lie parallel to one another, or be partially superposed at pleasure, while by turning the polarising prism the spectra can be made of any desired relative intensity. Suppose that we adjust the two prisms with their axes at right angles, and interpose the selenite used in the first experiment, which gave a band alternately in the red and in the green, we get now two spectra parallel to one another, the band in the red of the one occurring simultaneously with the band in the green of the other. The two bands are thus seen to be strictly complementary, for the band in the red of the one spectrum appears, attains its maximum, and vanishes simultaneously with the similar changes of the band in the green of the other spectrum. This coincident appearance of the bands, moreover, is independent of the inclination of the axis of the selenite to the plane of polarisation, the only effect of a change in which is to increase or diminish the maximum intensity of both bands alike, a result which, as has been noticed, does not hold with regard to the alternation of the two bands in the same spectrum.*

When the two prisms are placed with their axes parallel, so that the two images of the slit are seen alongside one another, and consequently the two spectra partially superposed and different colours mixed, the appearance of the bands is very striking. A band occurring in either spectrum is no longer black, but of the colour of that part of the other spectrum which coincides with it. The appearance is, in fact, as if a stripe had been cut out of the one spectrum through which the colour of the other spectrum is seen, while on either side of the band we have in striking contrast the colours due to the compounding of the different parts of the two spectra.

The beauty of the effect depends of course greatly on the extent to which the double image prism separates the two images. It should be so cut that the compound colours caused by the overlapping of the spectra shall be as different as possible from either of their constituent colours. The selenite should then be set at 45°, so as to make the spectra of equal and the bands of maximum intensity.

With films which give numerous bands the effect is very beautiful, and may be still further enhanced by rotating the polariser, when the bands will shift their position, at the same time changing their colours.

Experiments with Sections of Double Refracting Crystals giving Coloured Rings.

The coloured rings produced when polarised light is transmitted through a double refracting crystal cut perpendicularly to its axis, have always been

* See Note on p. 180.

admitted to be among the most beautiful of the phenomena which the science of optics can produce.

When homogenous light is used it is well-known that the rings assume entirely the colour of the light used, the spaces between the coloured rings being black.

The splendour of the phenomena, however, obtained by the use either of ordinary or of homogenous light, is incomparably inferior to that displayed by projecting the rings against the spectrum. The spectrum microscope is admirably suited for this exhibition.

The method I adopted was simply to place the section of the crystal immediately over the eye lens of the microscope, and between it and the analysing prism.

The rings are thus seen of every colour in the spectrum, alternating with jet black rings between each, those in the red being the broadest; and the breadth of the rings gradually diminishing to the most refrangible end of the spectrum.

It is impossible to give any satisfactory idea of the appearances by mere description, and no little skill or labour would be required to paint any adequate representation of the effects seen in some of the following combinations.

Take, as an example, a section of a crystal of sugar which gives a very fine system of rings. I have counted easily as many as forty-five when projected against the spectrum. This crystal is one of those which gives in polarised light two black brushes, not a black cross like Iceland spar. When the NICOL's prisms are at right angles the brushes are at their maximum intensity, and the spectrum with its series of rings is seen to be cut in two by the jet black brushes. When the analyser is turned through 90° the brushes which would now, if seen by ordinary polarised light, be white, are of every colour in the spectrum acording to the part of it they fall upon, and shaded off at their sides by a nebulous haze of colour through which the black rings are visible.

In intermediate positions of the analyser the brushes become entirely nebulous, so that the rings can be seen through their whole extent. In this position of matters the circle appears divided into four quadrants, and the rings are distinctly seen to be dislocated so to speak, *i.e.*, the rings in the alternate quadrants are pushed out so that each coloured ring in the one quadrant is continuous with a black ring in the next.

This effect is still better seen by circularly polarising the light before its passage through the crystal. The effect of this is a curious one. Instead of the circle being divided into four alternate quadrants, it is now divided into two semicircles, the rings in the one being alternate with those in the other. The semicircles are separated by two narrow coloured brushes which revolve with the analyser, and seem as if they swept out the black rings in the one

segment to be replaced by the coloured rings of the next. If we again circularly polarise the light by interposing a second circularly polarising plate between the crystal and the analyser, the brushes entirely disappear, and both the black and the coloured rings are continuous throughout, forming perfect circles.

When the analyser is rotated through 90°, the centre of the system which was formerly black is now coloured, and, at the same time, all the black rings have exchanged places with the coloured rings, the change being effected by a lateral displacement in opposite directions of the two halves of the circle.

If, for the second circularly polarising film, we substitute a film of a different thickness, the rings assume curiously distorted forms. With one film which I used the rings became ellipses, with another they all united so as to form a circular helix, which appeared to unwind like a screw as the analyser was turned.

The appearances produced by using different crystals are, of course, similar *mutatis mutandis.*

By circularly polarising the light before and after its passage through a crystal of nitre, the brushes are wiped out, and the lemniscates are beautifully seen, unbroken throughout.

When a crystal of Iceland spar is used, and the NICOL's prisms set with their axes inclined 45° we get eight segments, of which the four light segments look as if they stood out in relief against the dark segments, while the sections of the black rings, especially near the centre of the system, look more like straight lines than circular arcs, and form a system of octagons.

The effect upon the rings, produced by placing on the stage a film of selenite in the position in which it should give the black bands previously described, is a strange one. Instead of a black band occurring, the coloured ring belonging to that partof the spectrum is seen to split into two. It sends off a branch as it were from its lower part, which shoots across the adjoining black ring, and joins itself with the lower part of the next coloured ring. This last ring then in turn sends off a branch from its middle part, which in like manner unites with a third ring, which in turn does the same to its neighbour. All this takes place within the space which should be occupied by the black band.

The beauty of these last experiments, wonderful as it is, may be still further enhanced by the use of a double image prism as the analyser. The result is analogous to that obtained with the same arrangement in the case of the selenite previously described. We now get not only two spectra but two systems of rings which, by superposing the spectra, may be made to interlace with one another. Wherever a black ring of the one spectrum crosses a black ring of the other, the intersection is of course still black. Where a coloured ring of the one system crosses a black ring of the other, it retains its original colour; but if a

coloured ring crosses a coloured ring, the intersection is of the resultant colour of the two combined.

Still more complex figures are got by employing two or more crystals in combination.

Indeed, there is no end to the variety of exquisite beauty, both in colour and in pattern, which a little ingenuity may produce. Pigments would be almost as helpless as words in representing many of these. The appearance produced by a single crystal with a double image prism as analyser, may be not inaptly compared to a tesselated pavement of every colour made for a fairy palace, while that produced by combining two crystals may be said to resemble a suit of chain armour wrought for a fairy king in jewels of which no two are of the same hue.

Addition to the above Paper. By J. Clerk Maxwell, LL.D., F.R.SS. L. & E.

In Mr Deas' paper a number of interesting experiments are described, in which, by means of a spectroscopic microscope fitted with polarising and analysing prisms, the true nature of the phenomena observed by Brewster, Biot, and others, in plates of selenite, &c., is made exceedingly intelligible to the understanding, while, at the same time, the eye is satiated with new forms of splendour.

The subject is one to which the attention of experimenters is not so strongly directed as it was fifty years ago; and therefore it is desirable that the remarkably simple methods of observation here described, and the perfection with which the phenomena may be seen by means of modern instruments, should be more generally known.

In the text, the paper appears purely descriptive, without any theoretical application, and the æsthetic beauty of the phenomena might be assumed to be the object of the experiments. But the carefulness of the selection of the experiments and the faithfulness of the description make me think that the author himself looked at what he saw in the light of the theory of double refraction and the interference of light. I, therefore, think that a simple statement of the relation of the visible things here described to the results of theory would greatly increase the value of the paper; for in scientific education the identification of what is observed with what is deduced from theory is of more value than either the process of observation or the process of deduction.

This might be done as follows:—

Begin with the plane polarised light, the equations of motion of which are

$$x = c \cos nt \qquad y = 0.$$

Now let it pass through a plate of crystal of which the axis is inclined α to

the axis of x; and let this crystal produce a retardation whose phase is p in the light polarised in the plane of the axis

parallel to axis	$x' = c \cos \alpha \cos (nt + p)$
perpendicular to axis	$y' = c \sin \alpha \cos nt$.

Next, let the light fall on an analyser in a plane inclined β to the axis of the crystal. The analysed light will be

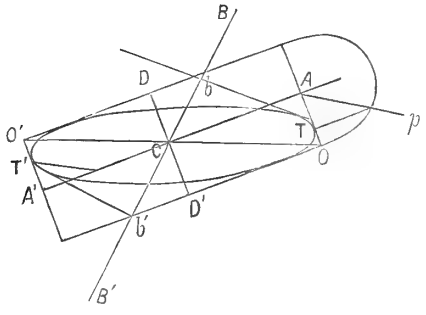
$$x'' = c \cos \alpha \cos \beta \cos (nt + p) + c \sin \alpha \sin \beta \cos nt.$$

The intensity of this light will be

$$c^2 \{\cos^2 \alpha \cos^2 \beta + \sin^2 \alpha \sin^2 \beta - 2 \sin \alpha \cos \alpha \sin \beta \cos \beta \cos p\}$$

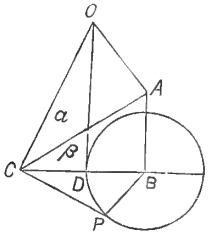
$$\text{or } \tfrac{1}{2} c^2 \left\{ 1 + \cos 2\alpha \cos 2\beta - \sin 2\alpha \sin 2\beta \cos p \right\}.$$

We may represent this whole process geometrically as follows :—



Let OCO′ represent the original polarised light, OCA the angle between the plane of polarisation and the axis of the crystal. The light is resolved into ACA′ and DCD′. Now, let a semicircle be drawn with radius OA, and let OAp = p be the phase of retardation; draw pT perpendicular to AO, and draw an ellipse with centre C and touching AO in T and also the other sides of the parallelogram. This ellipse is the path of the light emergent from the crystal. Now let BCB′ be the plane of the analyser. Draw Tb T′b' tangents to the ellipse perpendicular to BB′, then bCb' represents the amplitude of the emergent light.

The *result* of the process may be made still simpler thus :



Draw CO = c, in the plane of polarisation, CA parallel to the axis of the crystal, and CB parallel to the analyser. Draw OA perpendicular to CA, AB to CB, and OD to CB, then CB = $c \cos \alpha \cos \beta$, and BD = $c \sin \alpha \sin \beta$; make DBP = p, the phase of retardation, and BP = BD. Then CP represents the amplitude of the emergent light.

The emergent light will be either a maximum or a minimum when $p = 0°$ or $n\pi$.

The minimum will be zero, or blackness, only in the following cases,

1. When $\alpha + \beta = \frac{\pi}{2}$ and $p = 0$ or $2n\pi$.

2. When $\alpha - \beta = \frac{\pi}{2}$ and $p = (2n + 1)\pi$.

3. When $\alpha = 0$ and $\beta = \frac{\pi}{2}$.

4. When $\alpha = \frac{\pi}{2}$ and $\beta = 0$.

To compare our results with the experiments, we observe that for a given thickness of the crystal p is a function of the *kind of light,* so that in passing from one end of the spectrum to the other the value of p increases (or diminishes) in a continuous manner. When the film is thick, p will make several entire revolutions within the spectrum. When it is thin, there will be only one or two, or a fraction of a revolution. Take the case of a thick film, then there will be a certain set of black bands when $\beta = \frac{\pi}{2} - \alpha$. We may call these No. 1. For these $p = 2n\pi$.

When $\beta = \frac{\pi}{2} + \alpha$ there will be another set of black bands, No. 2, intermediate in position to No. 1. For these $p = (2n + 1)\pi$.

When $\beta = 0$ or $\frac{\pi}{2}$ the system of bands vanishes.

When $\beta = -\alpha$ the black bands of No. 1 become bright and of maximum intensity.

When $\beta = \alpha$ the black bands of No. 2 become bright and of maximum intensity.

When $\alpha = \frac{\pi}{4}$ all these phenomena are at their greatest distinctness.

In turning the analyser there is simply a dissolution of one system into the other, without motion of the system of bands in the case of a single plate of crystal. But if we place the crystal with its axis inclined 45° to the plane of primitive polarisation, and place above this a film of retardation $\frac{\pi}{2}$ with its axis parallel to the original polarisation, then we have as before for the light emerging from the first crystal,

$$x' = c\frac{1}{\sqrt{2}}\cos(nt + p) \quad y' = c\frac{1}{\sqrt{2}}\cos nt.$$

Resolving these rays in the direction of the axis of the second film, we have

$$x'' = \frac{1}{2}c\Big(\cos(nt + p) + \cos nt\Big)$$

$$y'' = \frac{1}{2}c\Big(\cos(nt + p) - \cos nt\Big),$$

and since x'' is retarded $\frac{\pi}{2}$ it becomes

$$x'' = \frac{1}{2}c\Big(\sin(nt + p) - \sin nt\Big),$$

y'' remaining the same. We may put these values into the form

$$x'' = c\cos\left(nt + \frac{p}{2}\right)\cos\frac{p}{2}$$

$$y'' = c\cos\left(nt + \frac{p}{2}\right)\sin\frac{p}{2}.$$

This shows that after emerging from the circular polarising film the ray is plane-polarised, that the plane of polarisation inclined $\frac{1}{2}p$ to that of primitive polarisation.

If the emergent light is analysed by a dispersion prism, and a NICOL's prism inclined β to the plane of primitive polarisation, there will be black bands (perfectly black) for all colours for which

$$p = 2\beta \text{ or } 2\beta + 2n\pi,$$

and as the prism is turned these bands will march forwards in a regular manner across the spectrum.

This very beautiful experiment, in which the phenomena of rotatory polarisation are imitated, is not so well known as it deserves to be. One form of it is due, I believe, to BIOT, and another to WHEATSTONE, but the arrangement here described is by far the most convenient.

When the second plate is thick, then for some points of the spectrum its retardation is $(2n+\frac{1}{2})\pi$. At these points the bands will move forwards when the analyser is turned. At an intermediate set of points the retardation is $(2n-\frac{1}{2})\pi$. At these points the bands will appear to move backwards. At intermediate points the retardation is $n\pi$. At these points the bands will not move, but will become deeper or fainter. I suppose this to be the explanation of the experiment described at p. 181, but the arrangement of the films is not very precisely described.

The experiments with the rings in crystals are very well described, and must be beautiful, but are not so instructive to a beginner as those with the selenite plates. Those, however, who have made out the meaning of the experiments first described have a good right to regale themselves with gorgeous entanglements of colour.

X.—*On the Oxidation Products of Picoline.* By JAMES DEWAR, F.R.S.E., Chemical Demonstrator in the University of Edinburgh, and Lecturer on Chemistry at the Edinburgh Veterinary College.

(Read 6th June 1870.)

The combined researches of ANDERSON and WILLIAMS on the basic compounds contained in coal tar have led to the discovery of two well-defined series of organic bases, called respectively the Pyridine and Chinoline series, the members of both of which possess the properties of nitrile bases. The isomerism between the pyridine and the aniline series of bases excited considerable interest at the time of its discovery. The subsequent researches of WILLIAMS on the products of the distillation of chinchonine led to the discovery of bases having the same composition as the members of the pyridine and chinoline series of coal tar. When first discovered they were supposed to be identical. Since that time, however, a careful examination and comparison of the tar series of bases with the chinchonine series has led Mr WILLIAMS to the interesting discovery that the two lutidines, as also the two chinolines, are in reality not identical, but isomeric. This introduces a greater complexity into the study of the constitution of these compounds.

I began this investigation in the summer of 1867 under the able direction of Professor AUG. KEKULÉ, in the University of Ghent. At that time the whole of the then known facts regarding the properties of these bases had been accumulated by ANDERSON and WILLIAMS, and by PERKIN, who had obtained pyridine from a naphthaline derivative. Save by this latter method the only process of preparation known was destructive distillation. All the attempts that had been made to elucidate the internal constitution and relationship of these bases had failed to yield positive results, their extreme stability in presence of the most powerful reagents presenting a barrier to investigation. In 1869 Professor ADOLPHE BAEYER made the brilliant syntheses of picoline through the action of tri-brom-allyl and of acryl aldehyd, respectively, on ammonia; and through the action of higher aldehyd homologues has shown the reaction to be general. Thus, by the synthetical labours of BAEYER, we have acquired for the first time a definite knowledge regarding the mode of formation and constitution of this class of organic compounds.

Having formerly employed permanganate of potassium in the oxidation of phenol (see Proc. Roy. Soc. Edin. Session 1866–67, p. 82), I naturally attempted the oxidation of these bases by the same agent; and I have since found that

A. W. HOFMANN had successfully employed it to oxidise chinoline into ammonia and oxalic acid. Finding the members of the pyridine series to be easily attacked by this reagent, I commenced a careful examination of the products of the oxidation of picoline, with the object of learning something regarding its internal structure. A preliminary note on the results obtained was communicated to the British Association at its Norwich meeting, 1868 (see Report Brit. Assoc. 1868).

I am indebted to my friend Dr RONALDS of Bonnington for a liberal supply of a quantity of bases that he had carefully prepared, with the object of instituting an investigation into these compounds himself. The crude bases placed in my hands had been repeatedly fractionated on a large scale, and the individual fractions were thus tolerably pure to begin with. Finding they contained traces of pyrrol and hydrocarbons, I redissolved in acid the fraction boiling from 130° to 160° C., and subsequently treated it in the way recommended by ANDERSON and WILLIAMS to purify these bodies. The mixture of bases thus obtained was subjected to a series of careful fractional distillations. With the object of effecting the best possible separation, I employed the method recommended by WARREN, and found it admirably suited to effect a comparatively easy separation, so far as fractional distillation can be made to yield a pure product. The bases were transferred to a retort connected with an ascending spiral of copper tube enclosed in a paraffine bath of large dimension, the temperature of which was continuously equalised by constant stirring. Five successive fractionations by this method gave a separation as complete as was necessary for the object I had in view. From the laborious researches of ANDERSON and WILLIAMS, we know that these bases for a large range of temperature have the same composition, and that perfectly pure products can be obtained only through the fractional precipitation of the platinum salts. Although I did not make an exhaustive separation by WARREN'S method, the fractionation was so effective that, by comparing the temperature of the boiling vapour in the retort with the temperature of the paraffine bath throughout the whole course of a distillation, a difference of 10° C. at starting gradually increased to 20°. No fraction that I obtained, separated in this process by a difference of 2° C. in the intermediate condenser, had a perfectly constant boiling point. On different occasions fractions separated in this way, boiling between 130° and 140° C., have been employed in the following experiments. Analyses of the platinum salts of portions boiling between those temperatures showed the fractions to be substantially picoline, with a possible trace of lutidine.

Picoline, as is well known, resists oxidation by the most powerful agents adapted for this purpose, nitric and chromic acids being without visible action, even at high temperatures. Of all oxidising agents, permanganic acid, or its

potassium salt, seems to be the most powerful. Having on a former occasion employed this reagent to effect the oxidation of phenol alcohol, I naturally investigated the action effected on these nitrile bases. I found that the whole of the members of this series of compounds could be readily oxidised by the use of this substance. The higher members of the series were oxidised more readily than the lower, but in all cases it was effected with ease and rapidity. The following is a description of the apparatus used in the experiments on the oxidation products of these substances and of the mode of conducting the operation. A flask, about three litres in capacity, was connected by a wide tube with a large reversed LIEBIG'S condenser, so as to effect a rapid condensation of volatile products and their immediate return to the field of chemical action. The flask having been placed on a sand bath, 150 grms. potassium permanganate, $1\frac{1}{2}$ litres water, and 25 grms. picoline were introduced, and the whole heated to near the boiling point. The reaction began suddenly, with great evolution of heat, necessitating the removal of the source of external heat. The reduction of the permanganate was completed in half an hour. After the contents of the flask had cooled, the oxide of manganese was separated by filtration from the strongly alkaline liquid, and washed repeatedly with boiling water. The alkaline liquid was then transferred to a flask, and the basic substances distilled off. The residual alkaline liquid was then concentrated by evaporation to 200 c.c. and 300 c.c. and dilute sulphuric acid (containing 70 per cent. H_2SO_4) added to it. After standing for some time this acid liquid became thick from a deposit of long white crystalline needles of a complex of new acids. In different experiments the relative proportions of the reacting substances were considerably varied, but the yield of the new acids in every case was small, a large portion of the picoline having been completely oxidised, while some of it had remained unacted upon. This must always be the case, as a large quantity of the original base, from the violence of the reaction, was driven away from the flask, and, when condensed, it fell back into a boiling liquid of increasing alkalinity, in which the base was comparatively insoluble. After separating, by filtration, the new crystalline acid referred to, the filtrate was transferred to a retort, and the volatile acids distilled off.

GENERAL RESULTS OF OXIDATION.—When the dilute alkaline fluid was taken immediately after the permanganate was exhausted, it was found to contain carbonate of potassium. When neutralized with hydrochloric acid and chloride of calcium added, a white precipitate of oxalate of calcium was obtained. The oxalate was mixed with a small quantity of some higher acid, probably malonic, as the per-centage of lime found was 36·3, oxalate containing 38·3 per cent. The quantity of volatile acid produced by the reaction was small. The presence of nitric and acetic acids, however, was readily proved. The surplus base remaining after the oxidation operation was transformed into the double

platinum salt, and a fractional crystallisation made. The platinum was determined in these different salts as follows :—

1st Crystallisation—0·177 grm. pt-salt gave 0·077 grm. pt=43·7 per cent.
2d „ —0·6910 „ „ 0·2102 „ =33·95 per cent.

The first sample agreed in composition with the double chloride of platinum and ammonium; the second, with that of a mixture of the double platinum salts of pyridine and picoline. There was produced by the reaction, therefore, carbonic, nitric, oxalic, acetic, and a complex of new acids, ammonia, and probably a small quantity of pyridine. The relative proportion of the products obtained depended on the quantity of the oxidising agent used, the volume of the solution, rapidity of the action, and the quantity of bases present in the field of action.

Di-carbo-pyridenic Acid $C_5H_3N\begin{cases}CO_2H\\CO_2H\end{cases}$.—The crystalline acid substance separated by adding excess of sulphuric acid to the concentrated alkaline fluid, after standing overnight was collected on a filter, and repeatedly crystallised from hot water (in which it was easily soluble) until free from oxalic acid and potassium salts. When first separated from the acid solution it appeared in long needles; but after several recrystallisations from water it was obtained in the form of perfectly colourless plates, resembling naphthaline. (The crystallographic constants of this acid have not yet been determined.) The crystals did not contain any water of hydration. The following are the results of the analyses of the acid and its silver salt :—

Acid.

Weight of acid taken,	0·2195 grm.
Carbonic anhydride produced,	0·0685 „
Water produced,	0·4040 „
Nitrogen found by Gottlieb's method to bear to the CO_2 produced, the proportionate vol. of,	1 to 14·2

Calculated centesimally these figures give—

	Sample.	$C_7H_5NO_4$.
Carbon,	50·19	50·29
Hydrogen,	3·47	2·99
Nitrogen,	—	—

*Silver Salt.**

As with the acid, the salt was dried at 100° C.

	I.	II.
Weight of salt taken,	0·8766 grm.	0·5456 grm.
Carbonic anhydride produced,	0·6985 „	0·4518 „
Water produced,	0·0554 „	0·0602 „
Weight of salt taken,	0·6980 grm.	0·3951 grm.
Silver obtained,	1·5111 „	0·6525 „

* I. and II. were samples of silver salts obtained from different experiments. I. was got by double decomposition of the sodium salt; II. from the ammonium salt.

Calculated centessimally these results give—

	I.	II.	$C_7H_3NAg_2O_4$.
Carbon,	21·73	22·58	22·04
Hydrogen,	0·70	1·22	0·78
Silver,	56·60	56·78	56·69

In order to determine the equivalent of the acid, I took 0·5392 grm. of acid dried at 100° C. and titrated with pure caustic soda solution, every 1·813 c.c. containing 23 mgrm. of sodium; 11·7 c.c. of soda neutralised the acid taken. The point of saturation was well marked. The equivalent of the acid, from this determination, was, therefore, 83·55; as determined by analysis of the silver salt it was 83·5. The atomic weight of the acid taken as $C_7H_5NO_4$ was exactly double the equivalent found, which, if true, would necessarily involve the acid being bibasic. In order to determine the basicity of the acid, the ammonium salts were the only combinations that I specially examined. 0·4739 grm. of the acid carefully treated with excess of ammonia, and dried at 100° C., increased in weight by 0·0481 grm., gain = 10·13 per cent.; gain on the acid ammonium salt of foregoing formula = 10·17 per cent. The neutral ammonium salt was extremely soluble in water, whereas the acid salt was much less soluble, and could readily be obtained in the form of fine silky needles when the solution was evaporated. From the above data there can be little doubt that the acid was bibasic, bearing the same relation to pyridine that phthalic acid does to benzol. The acid melted at a temperature of about 210° C., frothed, evolved a small quantity of carbonic anhydride, and emitted the readily recognisable smell of these bases. It was easily decomposed when heated with soda-lime, evolving a basic substance, no doubt pyridine. The mercury, copper, cadmium, and zinc salts were all readily soluble in water. The barium and calcium salts were also soluble, and were obtained by adding the respective chlorides to the neutral sodium or ammonium salt; they crystallised in minute prismatic needles. The silver salt of this acid was specially characteristic. On the addition of nitrate of silver to a solution of the acid or its neutral ammonium salt, a white gelatinous precipitate immediately separated out—it was insoluble in boiling water, and was not visibly affected by exposure to light. The insolubility of this salt would enable us more readily to separate the acid from the other products of the oxidation reaction than the process first quoted in this paper.

Along with the acid just described, as separated by the process detailed, there was found associated with it another acid substance having a very much higher atomic weight. The crystalline mass, obtained by the addition of sulphuric acid to the alkaline liquid from the oxidation operation, purified by solution in and recrystallisation from alcohol, and dried over sulphuric acid by means of an air-pump, had an equivalent weight of 121. The crystals were hydrated, and lost 4·9 per cent. of their weight when dried at 100° C. The sodium

salt of this mixture gave, on the addition of nitrate of silver, a gelatinous precipitate agreeing in appearance and composition with that got from dicarbopyridenic acid; it contained 56·6 per cent. of silver. The equivalent of this mixture, as determined by the composition of the ammonium salt dried at 100° C., was 336; 0·8335 grm. of acid mixture dried at 100° C., and treated with ammonia, increased in weight by 0·0422 grm. This acid substance, therefore, was clearly a mixture of dicarbopyridenic acid with some acid of a very much higher atomic weight. It remained solid when heated to 220° C., at which temperature dicarbopyridenic acid readily melted, and was much less soluble in water than the latter.

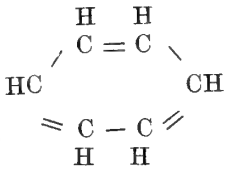
The difficulty and expense of obtaining these oxidation products in any quantity, prevented me from making the exhaustive investigation I would have liked.

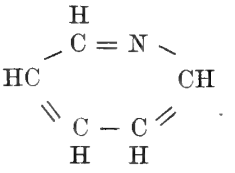
The formation of dicarbopyridenic acid by the oxidation of a mixture of picoline and lutidine, whether obtained from lutidine alone or by the complete destruction of picoline, is quite analogous to the formation of phthalic or teraphthalic acid, by the oxidation of the homologues of benzol, or by the complete destruction of benzol itself, as shown by CARIUS; the only difference being that CARIUS employed the lowest member of the benzol series, whereas picoline is the second known member of the basic series. The production of the same acid from pyridine itself would in no wise influence speculation regarding the constitution of the higher members of the series. For the present, we may consider pyridine as the nucleus from which all the other members of the series are derived. Although such a supposition must be considered purely hypothetical, in reality it is a great advantage to classify by analogy, relatively to other series, disjointed groups of organic compounds. The two series of bases, viz., the coal-tar and the chinchonine, bear the same empirical relation to pyridine that benzol does to its homologues and to naphthaline.

Benzol.	Toluol.	Naphthaline.
C_6H_6	C_6H_6	C_6H_6
	CH_2	C_4H_2
Pyridine.	Picoline.	Chinoline.
C_5H_5N	C_5H_5N	C_5H_5N
	CH_2	C_4H_2

Now, although it has not yet been proven that lutidine and chinoline have a similar formative relation to pyridine that tolnol and naphthaline have to benzol, still it is by no means an improbable analogy. The isomerism in the pyridine series, so far as is known, commences with the third member, lutidine, as found by WILLIAMS on comparing the chinchonine lutidine with the coal-tar lutidine; whereas the chinoline obtained from either source differs essentially in chemical characters. If we consider picoline as in all likelihood methyl-

pyridine, then the α and β lutidines may, in all probability, be represented as dimethyl-and ethyl-pyridine respectively, and we would expect the dimethyl-pyridine to give directly dicarbopyridenic acid, or an isomer, on oxidation. Pyridine may be written graphically as benzol in which nitrogen functions in place of the triatomic residue CH‴, and thus may be represented as a closed chain,—





And, considering the stability and mode of formation of these bases it is not at all improbable that they may not be produced by the simultaneous action of acetylene and its derivatives on hydrocyanic acid; thus as three molecules of acetylene condense and form benzol, so may two molecules of acetylene, and one of hydrocyanic acid, condense and produce pyridine.

There is a large class of substances that bear the same relation to the monamines that dicarbopyridenic acid does to pyridine, with this difference, that the best known are all monobasic instead of being bibasic acids. Thus glycocol, alamine, leucine, and their homologues, may be looked upon as the monocarbo-acids of the ethylamines, in which the carboxyl radicle is united directly to the carbon, the isomeric carbamic acids (or urethanes, as they are called) being the derivatives in which the carboxyl is united directly to the nitrogen,—

Ammonia.	Methylamine.	Glycocol.	Methyl-carbamic Acid.
H	CH_3	CH_2CO_2H	CH_3
N H	N H	N H	N H
H	H	H	CO_2H

Analogous derivatives are obtained from the aromatic ammonias. A class of derivatives similar to the above, must necessarily be derivable from the diamines. In the case of the nitrile bases or triamines, only derivatives could be obtained analogous to glycocol and its homologues. Bodies of a like constitution to glycocol readily break up into carbonic anhydride, and the corresponding ammonia; the reverse transformation has not yet been effected. The amido-bibasic acids bear the same relation to the monamines that dicarbopyridenic acid does to pyridine, with the exception of the difference in the constitution of the closed nitrile nucleus. No bibasic acid, other than pyridenic, has been discovered. A strictly analogous compound, in the monobasic series, is the acid carbo-pyrrolic, $C_5H_5NO_2$, which bears a similar relation to pyrrol that the amido-mono-carbon acids do to the ammonias, only that the pyrrol, although a nitrogenous body, is not, strictly speaking, a nitrile base. But the close analogy

between pyrrol and true nitrile bases, they being simultaneously produced in the majority of reactions, would lead us to expect a like class of derivatives being obtainable from pyridine.

HUBNER (Ann. Chem. u. Pharm., vol. 141) has described the oxidation products of nicotine, got by the action of sulphuric acid and bichromate of potassium. In that memoir he describes an acid so obtained, having the formula $C_5H_5NO_2$. This acid is identical in composition with mono-carbopyridenic acid. The base nicotine itself differs from dipyridine by only four hydro-

Nicotine.	Dipyridine.
C_5H_7N	C_5H_5N
C_5H_7N	C_5H_5N

gens; and as the nucleus of nicotine is a nitrile nucleus, it is not at all improbable that this acid may be a member of the series to which dicarbopyridenic belongs, so that nicotine may be similarly constituted to ANDERSON'S polymerised bases.

The stability of these bases to the majority of reagents (especially the primary member of the group, pyridine) would predispose us to look upon it as analogous to benzol, and to suppose that the atoms are symmetrically grouped. The syntheses of BAEYER support this view, and there is not any reason why we may not have as many stable derivatives from this nucleus as from benzol. I have already pointed out the analogy between the chinoline series and the pyridine series; and in a short time I hope to be able to publish details supporting the theoretical relations above given.

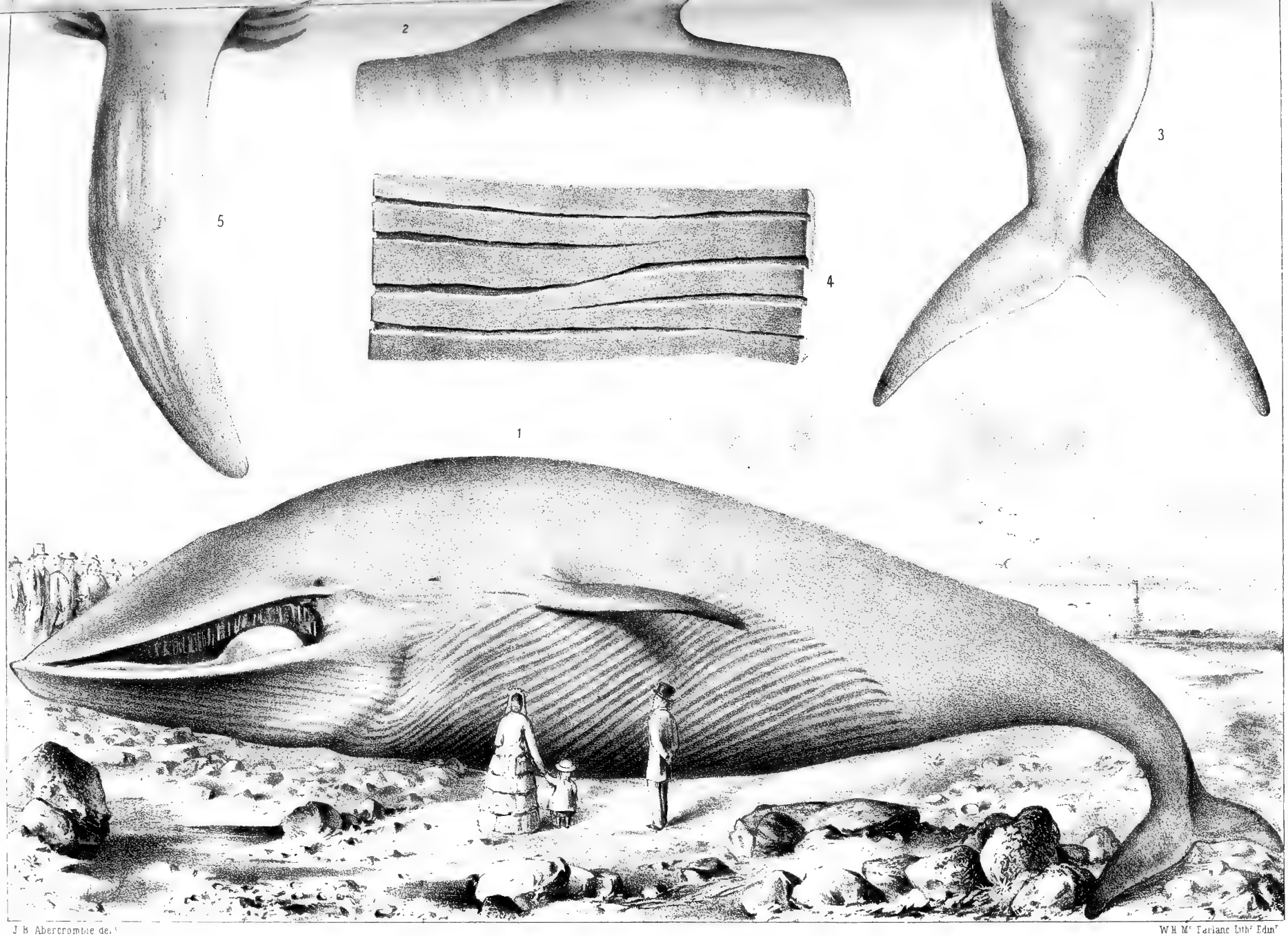
In the meantime, the following analogies may be pointed out between benzol- and nitrile-derivatives; thus—

Benzol.	Naphthaline.	Anthracine.	Pyridine.	Chinoline.
C_2H_2	C_6H_4	C_6H_4	C_2H_2	C_5H_3N
C_2H_2	C_2H_2	C_2H_2	NCH	C_2H_2
C_2H_2	C_2H_2	C_6H_4	C_2H_2	C_2H_2

Indol, from its general characteristics, evidently belongs to the pyrrol series, the following showing, in all probability, the relative structure of indol and pyrrol:—

Indol.	Pyrrol.
C_6H_4	C_2H_2
N H	N H
C_2H_2	C_2H_2

According to this hypothesis indol is simply benzol-pyrrol.



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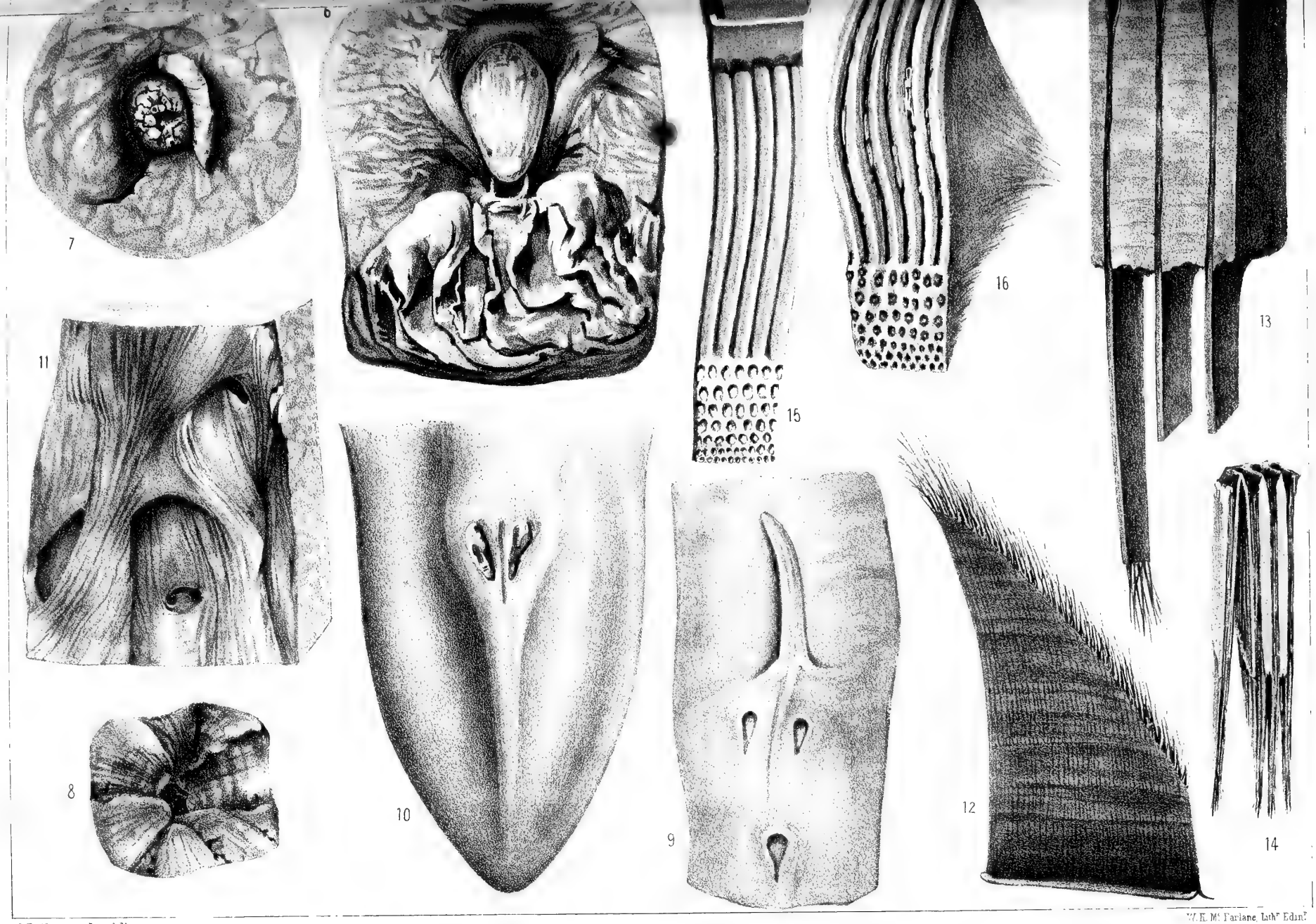

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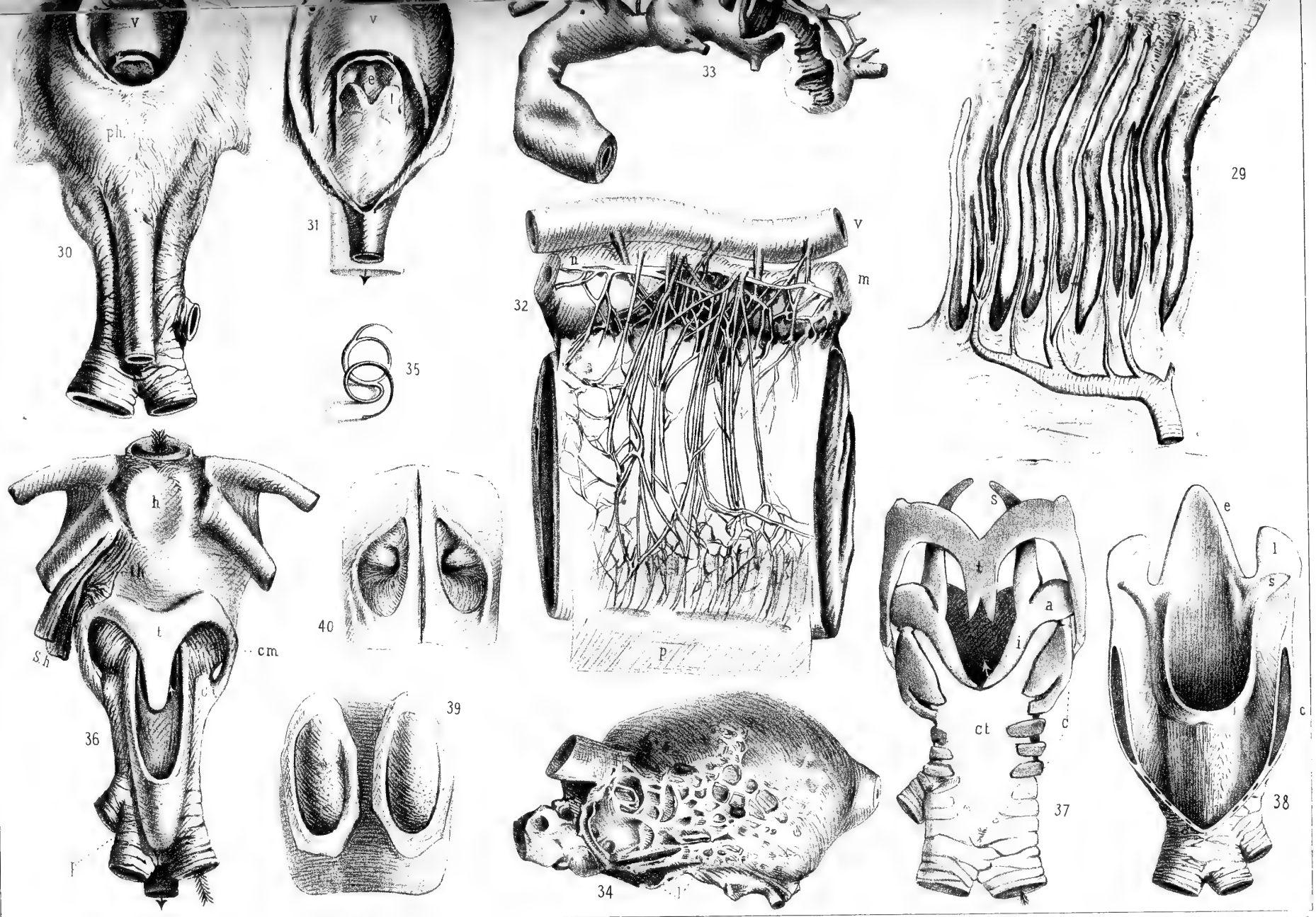

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W H. M.c Farlane, Lith.r Edin.r

XI.—*An Account of the Great Finner Whale* (Balænoptera Sibbaldii) *stranded at Longniddry.* Part I. The Soft Parts.

By Wm. Turner, M.B. (Lond.), Professor of Anatomy in the University of Edinburgh. (Plates V., VI., VII., VIII.)

(Received November, 1870.)*

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On the 3d November 1869, a huge Finner whale was stranded on the beach at Gosford Bay, Longniddry, Firth of Forth.

Most of the large Fin whales which have been examined by British and Continental anatomists have been found floating dead on the surface of the sea, and have then been towed ashore by their captors. But, from the account which was given in the Edinburgh daily newspapers, it would appear that, for some days previously, this animal had been recognised by the fishermen, swimming to and fro in the Firth. On the morning of the 3d it was seen from the shore, blowing with great violence from its nostrils, flapping its huge tail, and obviously struggling to disengage itself from the rocks and shoals, amidst which an unusually high tide had permitted it to wander. Shots were fired at it, and, from the wounds produced, blood poured forth which tinged the surrounding waves. As the tide receded, the animal was fairly stranded; and, after some vigorous but ineffectual attempts to disengage itself from its position, it slowly died. The animal lay some yards above low-water mark, so that for several hours each day it could be examined, and photographs taken from various points of view.

Under the powers conferred by Act of Parliament, the carcase was taken possession of by the receiver of wrecks for the Board of Trade and sold by public auction. It was purchased by Mr John Tait, Oil Merchant, Kirkcaldy, for L.120. After lying for a fortnight on the beach at Longniddry, a strong rope

* A preliminary account of this animal, illustrated by a number of specimens, photographs, and drawings, was read to the Society on the 20th December 1869, and an abstract of this communication was printed in the Proceedings of that date. By permission of the Council I have been allowed to supplement the preliminary notice with additional observations, and to extend it in a form for the Transactions of the Society.

was secured around the root of the tail, and, when afloat at high water, it was towed by a powerful steamer to Kirkcaldy, a town on the opposite shore of the Firth, distant about ten miles.

It was flensed on the beach, immediately to the east of Kirkcaldy harbour; and, as this could only be done at low water, the process of removing the blubber, taking out the fat within the abdomen, cutting off the baleen and flesh, disarticulating and removing the bones, occupied several men for nearly a month.

As one of the largest sized whalebone whales comes so very seldom within comparatively easy access of a great city, the opportunity was taken by crowds of persons to inspect the huge creature, not only as it lay on the beach at Longniddry, but whilst the process of cutting up was going on at Kirkcaldy.

As the classification and structure of the larger Cetacea possess many interesting points for investigation, I gladly availed myself of the presence of this rare visitor to devote such time as I could spare, in the midst of the work of the University session, to its examination.

The colour, general form, and dimensions of the animal were observed when the whale was lying on the shore at Longniddry. The observations on the internal structure were made as it was being cut up at Kirkcaldy, or on specimens which were brought over to the Anatomical Museum of the University, and submitted there to a more careful examination than could have been conducted on the sea beach.

The distance from Edinburgh at which the whale was lying, during the flensing, rendering a journey by rail and steamer necessary at each visit, the exposed position of the animal on the sea beach below high-water mark making access to it practicable only at low water, the great bulk of the creature, the difficulty of getting at the internal parts owing to the size of the cavities, the greasy, slippery condition of all the surroundings, and the impediments offered to handling or removing the viscera on account of their magnitude and weight, have made the examination of this whale a very laborious task. For these reasons, as well as from the putrid state into which the carcase passed, the extremely offensive gases generated by so huge a mass of putrifying flesh, and the great heat evolved by its decomposition, it was impossible to study many of the structures to which I should have wished to have devoted my attention. In many respects, therefore, I regret to say that my description will necessarily be incomplete and fragmentary.

In conducting the examination, I was most ably assisted by the thoroughly cordial and, I may say, enthusiastic, co-operation of my assistant, Mr Stirling, and my pupils, Mr Millen Coughtrey and Mr James Foulis, to whom I take this opportunity of expressing my thanks for the important aid which they rendered. To Mr John Tait of Kirkcaldy I and my assistants are indebted for

permission to examine the parts as they were exposed during the flensing, and to remove such specimens as could conveniently be taken away.

External form and dimensions.—The whale was a female. When I first saw the animal on Gosford beach, it was lying with its head pointing inland, and it rested on the right side of the belly, chest, and right lower jaw. The middle line of the belly was in contact with the ground, and the under surface of its horizontal tail lay on the shingle. The head, owing to its great weight, had fallen over to the right, so that it overhung the right lower jaw, and permitted the whole length of the inner surface of the left half of the lower jaw, and a large part of the dorsum of the tongue to be seen, together with the outer edges of the baleen plates on the left side (Plate V. fig. 1).

The length of the animal, measured with a graduated tape-line along the curve of the middle line of the back from the tip of the lower jaw to the end of the tail, was 78 feet 9 inches. The girth of the body immediately behind the flipper was estimated at 45 feet, dimensions which it preserved almost as far back as the extent of the abdominal plicæ, behind which it tapered off rapidly to the tail. Its girth in line with the anal orifice was 28 feet, whilst around the root of the tail it was only 7 feet 9 inches. In front of the flipper the girth was considerable, as far forward as the swell or greatest projection of the lower jaw, but in front of this it tapered off to the symphysis. The lower jaw arched outwards and forwards with a wide sweep from the angles of the mouth; then the two halves converging met at the symphysis and formed there a keel-like ridge. The tip of the lower jaw projected $1\frac{1}{2}$ foot beyond the tip of the upper jaw. The inner surface of the lower jaw was bevelled off close to its upper border, so as to admit the edge of the upper jaw within it. The length from the angle to the tip of the mouth, along the upper curved border of the lower jaw, was 21 feet 8 inches, and 17 feet 4 inches in a straight line.

The dorsum of the upper jaw was not arched in the antero-posterior direction as in the *Balæna mysticetus*. It sloped gently upwards and backwards to the blow-holes, from which a low but readily recognised median ridge passed forwards on the beak, gradually subsiding some distance behind its tip. On each side of this ridge was a shallow concavity. Immediately in front of the blow-hole the ridge bifurcated, and the forks passed backwards for several inches enclosing the nostrils, and then subsided. The outer borders of the upper jaw were not straight, but extended forward almost parallel to each other from the angle of the mouth for some distance in a gentle curve, and then converging in front formed a somewhat pointed tip. Their rounded palatal edges fitted within the arch of the lower jaw. The transverse diameter of the upper jaw over its dorsum between the angles of the mouth, was 13 feet 3 inches.

From the blow-holes the outline of the back curved upwards and backwards, it was uniformly smooth and rounded, and for a considerable distance presented

no dorsal mesial ridge. But somewhat in front of the posterior fourth of the back a ridge appeared, which culminated in the dorsal fin. Unfortunately the height of this fin could not be taken, as the summit had been cut away before I saw the animal. It was triangular in form, its anterior border convex, its posterior border falcate, whilst its apex had obviously projected upwards and backwards. A line drawn from its posterior border vertically down the side of the whale reached the ventral mesial line some distance behind the anus. From the tip of the lower jaw to the anterior border of the dorsal fin was 59 feet 3 inches. Behind the dorsal fin the sides of the animal sloped rapidly downwards to the ventral surface, so that both the dorsal and ventral mesial lines were clearly marked, and the sides tapered off backwards to the tail.

The lobes of the tail curved outwards and backwards from the terminal part of the sides of the animal; a rounded interlobular median notch marked the termination of the caudal spine, and separated the two lobes from each other. The anterior border of each lobe was rounded, and convex from root to tip, the posterior was sharp, and concave from root to tip; the tip was pointed and the surfaces flattened. The greatest girth of one of the tail lobes was 5 feet 8 inches, whilst the distance between the tips of the two lobes was somewhat more than 16 feet.*

The ventral surface of the throat, and the sides and ventral surface of the chest and belly, were marked by numerous longitudinal ridges and furrows. Some extended as far forward as the symphysis of the lower jaw, others to the angle of the mouth; some mounted as high as the root of the flipper, and even above its posterior border. These folds terminated at their hinder ends with great regularity along a line, which commencing some distance behind the root of the flipper sloped obliquely downwards and backwards to the ventral surface. The ventral folds were consequently the longest, one about the middle of the belly measured 45 feet. The number of these folds on each side of the ventral mesial line it was difficult exactly to determine, on account of the position in which the whale was lying, but at least thirty appeared to be present, though as a ridge occasionally bifurcated or gave off a branch, and as, after some time, its forks blended with adjacent ridges, the number necessarily varied in different localities. When I first saw the animal the furrows separating the ridges were not more than from $\frac{1}{4}$ to $\frac{3}{4}$ an inch broad, whilst the ridges themselves were in many places 4 inches in breadth, but as the body began to swell by the formation of gas from decomposition, the furrows were opened up, became wider and shallower, and the ridges underwent a corresponding diminution in breadth. At the same time a considerable change took place in the contour of the body in the thoracic and abdominal regions, which presented

* The extreme ends, probably one foot from each lobe, had unfortunately been cut away before the measurement was taken.

a huge lateral bulging, giving a greater girth than when it first came ashore. Close to the posterior ends of the mesial abdominal plicæ was a deeply puckered scar, the umbilicus.

The flipper projected from the side of the body 31 feet 4 inches behind the tip of the lower jaw, measured in a straight line, and 14 feet behind the angle of the mouth. It curved outwards and backwards, terminating in a free pointed end. Its surfaces were flattened; its anterior border rounded and convex from root to tip, measured 12 feet 3 inches; its posterior border concave from root to tip 10 feet, whilst its girth at the root was 9 feet 6 inches. The distance between the two flippers, measured over the back, between the anterior borders of their roots, was 18 feet 6 inches.

The slit-like entrance to the female passage was situated 22 feet in front of the fork of the tail. Its antero-posterior diameter was 16 inches. It was bounded laterally by elongated prominent folds of the integument, which represented the labia majora, and were indented by longitudinal furrows. In front of the aperture was a rounded elevation representing the mons, which was placed 10 feet behind the longitudinal plicæ on the middle of the belly. Behind the mons was a deeply depressed part of the integument, immediately posterior to which was a thick clitoris, triangular in its outline. Its length was 6 inches, the breadth at the root 4 inches (Plate VI. fig. 6). The clitoris curved backwards, and overlapped the external orifice of the urethra, which orifice was surrounded by a well-marked fold of mucous membrane. Both on its superficial and deep aspects it presented a rugose appearance. On each side of the root of the clitoris a projecting fold lying between the labia majora passed backwards, external to the urinary meatus. These two folds formed the labia minora; they bounded the vestibule, and their inner surfaces, as well as the floor of the vestibule, possessed a number of complex ridge-like elevations of the mucous membrane. When this membrane was cut through, a quantity of erectile tissue, in which were many large veins, was seen. Eight inches on each side of the female passage was a funnel-shaped elevation of the integument, at the summit of which a circular aperture, which readily admitted the tips of the fingers into a fossa about 4 inches deep, was seen. Projecting from the bottom of this fossa, but not through the circular aperture at its summit, was a large nipple about 3 inches long, which possessed an orifice at its free end—the termination of the great lacteal duct—into which the forefinger could be passed. A number of pedunculated papillæ were situated at the summit of the nipple around this orifice (fig. 7).

Thirteen inches behind the female passage was the orifice of the anus, which was small and contracted, but could easily be dilated so as to admit the hand. The integument immediately around the orifice was rugose, and in the neighbourhood both of the intestinal and genital openings the skin was

indented by several longitudinal furrows (fig. 8). A well-marked sphincter was observed beneath the integument around the anus. The mucous membrane at the anal end of the rectum had a blackish tint.

The eye was situated immediately above the angle of the mouth, from which it was 1 foot 6 inches distant. The fissure between the lids lay antero-posteriorly. The ear orifice was a narrow slit situated in a line behind the eye, from which it was distant 3 feet 10 inches. The transverse distance over the dorsum between the two eyes was 11 feet 5 inches, the corresponding distance between the two ears was 13 feet 7 inches.

The blow-holes were placed in the fossa between the two subdivisions of the dorsi-mesial ridge of the beak. Two longitudinal slits or nostrils, each large enough to admit the extended hand, were separated by an intermediate septum. Anteriorly the slits were only 4 inches asunder, but owing to their divergence the posterior ends were 15 inches apart, and the transverse diameter of the septum was correspondingly increased. The upper surface of the septum was marked by a longitudinal mesial groove. The antero-posterior diameter of the blow-holes was 1 foot 6 inches. From the tip of the lower jaw to the anterior end of the blow-holes, 14 feet 9 inches. From the anterior end of the blow-holes to the mesial notch of the tail 64 feet.

Colour.—On the dorsum of the beak and of the cranium, on the back of the body, and for some distance down its sides, the colour was dark steel grey, amounting in some lights almost to black. On a line with the pectoral flipper the sides were mottled with white, and on the ventral surface irregular, and in some cases, large patches of a silvery grey or milk whitish tint were seen. An experienced whaling seaman, Mr Walter Roddam, who had charge of the carcase, told me that he had repeatedly seen this kind of whale in the northern seas, and stated that, owing to the silvery hue of the belly, it was known to the whalers by the name of "silver bottom."* The surfaces of the clitoris and of the labia minora were mottled with black and silvery grey tints like the skin of the belly.

The dorsal fin was steel-grey or black, except near its posterior border, where it was a shade lighter and streaked with black lines. The anterior margin of the lobes of the tail, its upper surface near the root and for the anterior two-thirds, were black, whilst the posterior third of the same surface and the interlobular notch were lighter in tint. The ventral folds had a light sepia colour, and the furrows were not so dark as the ridges. The upper surface of the flipper was steel-grey, mottled with white at the root, at the tip, along its

* In the 2d vol. of Dr Scoresby's Account of the Arctic Regions, p. 531, it is stated, on the authority of Captain Day, that amongst the whales pursued by the southern whale-fishers is one called "sulphur bottom," a species of Fin whale of great length and swiftness. Can it be that sulphur bottom is a corruption of silver bottom? and that this whale frequents both the northern and southern oceans?

posterior or internal border, and on the under surface; white patches were also seen on the upper surface near the tip, and here they were streaked with black lines running in the long axis of the flipper. White patches also extended from the root of the flipper to the adjacent parts of the sides of the animal. The outside of the lower jaw was black, whilst the inside was streaked with grey and brown.

A few days after the death of the whale, the scarf skin had become loose, and large portions of it had separated, leaving the pinkish-white cutis exposed, and giving therefore a different colour to these parts of the integument than they had originally possessed. This circumstance is worthy of note, and may serve to explain appearances which have been described by some authors in connection with the colour of the skin in specimens of fin whales which they have examined. The surface of the skin was smooth and shining. No parasites were found attached to it, and no hairs or bristles were observed to project from any part of its surface.

Although the animal had reached the enormous length of nearly 80 feet, yet it had not attained its perfect adult state. For, as the subsequent examination of the skeleton showed, the disk-like epiphyses of the thoracic and lumbar vertebræ were not yet united to the bodies of those bones. The whale, therefore, was at the period of growth which, as Professor FLOWER has pointed out,* may very appropriately be termed "adolescent."

Fœtus and Membranes.—When the whale was lying on the beach at Longniddry, the seaman in charge told me that he believed the animal to be in calf. On the fourth day after the operation of flensing on the beach at Kirkcaldy had commenced, as I was watching a man taking away the blubber and muscles from the posterior part of the side of the abdominal wall, I observed an elongated, dark-coloured mass lying loose amidst the coils of intestine, almost opposite the umbilical scar. I requested the man to hand it to me, and at once recognised it to be a wreath of young baleen about 4 feet long, which had obviously become detached from the roof of the mouth of a young animal, and had by some means or other escaped into the abdominal cavity of the parent. The discovery of this baleen clearly proved that the whale was in the gravid state. We at once commenced to remove a larger portion of the abdominal wall in order to obtain a view of the uterus, but before this could be accomplished, the rising tide compelled us to cease our operations. As this happened on a Saturday, work could not be resumed until the Monday following, and as my University duties prevented me from being present, the search was conducted by Messrs COUGHTREY and FOULIS, who after several hours of hard work exposed the head of the calf by the removal of a mass of blubber from the right

* Proc. Zoological Society, Nov. 8, 1864.

side of the neck of the parent animal. The head of the calf indeed was so far forward that the tip of its beak was only 2 feet 9 inches behind the condyle of the mother's right mandible. An additional mass of blubber was then taken away from the exterior of the ribs on the right side, when more of the calf was exposed. It was lying obliquely between the blubber and the muscles which covered the outer surfaces of these ribs, and the space in which it was contained had obviously been formed by a forcible separation of the blubber from the subjacent muscles; for when the blubber was cut through, the pressure on the calf, owing to its position between a weighty mass of blubber and the elastic ribs, was so great that its head protruded through the incision, and even partially tore through the superficial textures.

The lower jaw of the calf was directed towards the ventral surface of the mother, and the left side of its body was in relation to the outer surface of her right ribs, and its tail was directed to her abdominal cavity. After the removal of an additional portion of blubber, the calf was extracted by my assistants, and in the process of removal it was observed that about 5 feet from the tail the body of the calf was so twisted on itself, that the position of the two lobes of the tail was reversed. A large quantity of the fœtal membranes lay alongside of the calf, more especially near its caudal end; but they were torn, and had lost their bag-like form. Some coils of the intestine were also situated beside the tail. It is much to be regretted that the uterus could not be preserved in the course of this examination. The huge size of the coils of the intestine, and the desire which the men employed had to get rid, on account of the smell, of the contents of the abdominal cavity, rendered it impossible to make such an examination of these viscera as was desired.

From a consideration of the position of the calf there can be no doubt that either immediately before or after the death of the mother, the fœtus had been disconnected from its proper attachments and extruded into an artificial space external to the abdominal cavity. The torn state of the fœtal membranes and umbilical cord, the presence of coils of the intestine in the space in which the fœtus was lying, and the loose mass of baleen in the abdominal cavity of the mother, all point to a rupture not only of the uterus, but of the wall of her abdomen, which had permitted the passage out of the cavity both of the fœtus and of portions of the gut.

To what cause, then, are we to ascribe the rupture and consequent displacement? Some of those who examined the whale were of opinion that they had been occasioned by a severe injury sustained by the mother prior to, or at the time she came ashore. But I am rather inclined to think they must have occurred whilst she was being towed by the tail across the Firth from Longniddry to Kirkcaldy. For, during the two weeks she lay on the beach at the former place, decomposition had advanced to a considerable extent, putrid

gases were disengaged, and consequent softening of the soft parts had occurred. As the sternum is short, and only articulates with the first pair of ribs, and as the inner ends of the remaining ribs diverge considerably from each other, and have no strong attachments in the ventral mesial line, the great pressure of the sea on the wall of the abdomen, as she was towed by the tail, would tend to rupture the uterus and abdominal wall, to drive the contents of the abdomen forwards towards the head, and to force the fœtus into the position in which it was found.

Owing to the displacement of the fœtus, the dissection of this animal does not enable me to state with certainty the normal position of the fœtus in utero in this cetacean. Very little indeed is known of the uterine position of the fœtus in this group of mammals. In a communication made to the Royal Belgian Academy,* M. VAN BENEDEN figures the position in utero of the fœtus in *Globiceps*. Its head is directed to the maternal genital orifice, its body is bent, and the tail is folded backward under the thorax, so as to lie close to its flipper. He believes that the fœtus of *Balænoptera rostrata* has the same position in utero, and doubts the statement made by M. BOECK, that the young of *rostrata* is born first by the tail. In the Longniddry *Balænoptera*, on the other hand, the head of the fœtus was directed towards the head of the mother; and unless we suppose that during the displacement a complete revolution in the relative position of its caudal and cephalic ends had taken place—an occurence which, owing to the great length of the fœtus, scarcely seems possible—the uterine direction of the young one would have been with its tail towards the maternal genital passage.

The gravid state of the whale necessarily exercised an influence on its shape, more especially by increasing its girth in the abdominal region—a circumstance which should be kept in mind in comparing the drawing of this animal (fig. 1) with those which have been given by other naturalists of the Finners which have come under their observation.

The form of the fœtus differed in several particulars from that of the mother. Its greatest girth was around the head, from which it tapered forwards along the beak, and backwards to the root of the tail. From the unexpanded condition of the lungs, and the flaccid state of the hollow viscera of the abdomen, the thoracic and abdominal cavities had not attained their proper girth, and the body and caudal end of the fœtus presented a peculiar, elongated, worm-like appearance. The dorsal fin did not rise so abruptly in the fœtus as in the adult, so that it was difficult to determine its exact antero-posterior length. Its posterior border had a well-marked falcate curve (Plate V. fig. 2).

The fœtus was a male. The penis, 11 inches long, hung pendulous from the ventral surface, and at each side of its root a crescentic fold of skin arched out-

* Bulletins, vol. xx. 2d series, No. 12.

wards (Plate VI. fig. 9). Behind each of these folds was the mouth of the shallow nipple fossa; the nipple was rudimentary, and concealed by the prominent anterior border of the fossa. The posterior border was feeble, and here the fossa blended with the general surface of the abdominal wall. Passing backwards, midway between these fossæ, was a well-defined raphé reaching to the anus. The abdominal wall was much torn in front and at the root of the penis, and the exact attachment of the umbilical cord could scarcely be recognised, but it was estimated to be connected about 18 inches in front of the root of the penis; for the cord, though carefully divided at the time when the fœtus was removed from the mother, had been used, along with the penis, as a convenient object to lift with by the men employed to carry the calf, and consequently both they, and the part of the wall to which they were connected, had sustained injury. The tail was subdivided into two elegantly curved horizontal lobes (fig. 3). The sides and ventral surface showed the characteristic plicated appearance (fig. 4). On the top of the head, 1 foot 5 inches behind the blowhole, was an oval patch 1 inch long by $\frac{3}{4}$ths broad. It was raised somewhat above the level of the integument. The shape of the flipper is represented in fig 5.

The colour of the integument was a warm grey, mottled here and there with yellow. Patches of dark steel-grey pigment were observed on the back; but none of the light silver-grey tints, seen in the large whale, were observed on the belly. I believe that desquamation of the cuticle had taken place very extensively before the calf came into my possession.

I had anticipated that the comparatively small size of the fœtus would, by giving me greater command over the dissection, have enabled me to have worked out all those points in the anatomy of this whale, which I could not overtake in the older animal. But in many respects I was disappointed, for the weight of the fœtus, which amounted to about half a ton, and its length of almost twenty feet, rendered it a most unwieldy object to transport to the Anatomical Museum. Moreover, putrefaction had to some extent advanced before I had the opportunity to examine it; the abdominal wall was torn, and the viscera in that cavity were so much injured, that but little definite information respecting the stomach and intestines could be obtained. The muscles also had undergone a remarkable kind of decomposition; the odour exhaled from them was peculiarly acrid and offensive, which, together with their softened condition, rendered it impossible to make a proper study of those important parts of the locomotory system. The bones of the skull and spine were also to some extent displaced.

A number of measurements were taken, a table of which I subjoin; but in consequence of the displacement just referred to, some of the dimensions are probably not absolutely exact, but are to be regarded as the closest approximation which could be obtained:—

	Feet.	Inches.
Length of male fœtus,	19	6
From tip of lower jaw to posterior end of blow holes,	3	9
From posterior end of blow-holes to posterior border of dorsal fin,	10	8
From posterior border of dorsal fin to interlobular median notch of tail,	5	1
Antero-posterior diameter of blow-holes,	0	6
Transverse diameter of blow-holes,	0	$3\frac{1}{2}$
From tip of lower jaw to angle of mouth in a straight line,	3	11
From tip of lower jaw along curve to angle of mouth,	4	6
From angle of mouth to anterior border of root of flipper,	1	10
From tip of lower jaw in a straight line to anterior border of root of flipper,	5	9
Length of flipper along anterior border,	3	7
Greatest diameter of flipper from anterior to posterior border,	0	9
Girth of flipper at root,	1	$10\frac{1}{2}$
Girth of body just behind dorsal fin,	3	6
Girth round root of tail,	1	6
Between extreme points of tail-lobes in a straight line,	4	7
Between extreme points of tail-lobes along posterior concave border,	5	6
Greatest girth of tail-lobe,	2	7
From median notch of tail to anal orifice,	6	2
Transverse distance between nipple fossæ,	0	3
From anal orifice to midway between nipple fossæ,	0	$8\frac{1}{2}$
From nipple fossa to fold of skin at root of penis,	0	$5\frac{1}{4}$
Length of penis,	0	11
Vertical diameter of dorsal fin,	0	$6\frac{1}{2}$
Greatest transverse diameter of cavity of mouth,	1	9

A vertical line, drawn from the root of the posterior border of the dorsal fin to the ventral mesial line, was $16\frac{1}{4}$ inches behind the anal orifice.

The displacement of the fœtus and the torn state of the membranes did not give me the opportunity of observing the exact relations of the latter to the fœtus and to the mucous surface of the uterus. Although several square yards passed through my hands, yet I did not succeed in recovering the whole extent of these important structures. Notwithstanding these deficiencies many points of interest bearing on the placentation of the cetacea were observed.

The outer surface of the chorion had the general villous appearance which is characteristic of the diffused form of placenta. In my first, and somewhat hurried inspection of this membrane, I did not notice any portion which did not possess villi. But on a second examination, made at more leisure on the membrane preserved in spirit, I observed that a portion of the chorion was bare. Unfortunately this had been torn across and a portion lost, so that the proper form of the non-villous part could not be ascertained. It had apparently, however, been of some extent, for the portion preserved was oblong in form, and measured 11 inches by 3. In all probability it had formed a part of one of the prolonged poles of the membrane.

The villi began at the edge of this bare part by a well-defined line; immediately beyond and parallel to which the chorion was doubled on itself, so as to form a

strong marginal fold, which projected for about one inch, and was thickly studded with villi on its surface and free edge. (Plate VII. fig. 17.) A second fold, also covered with villi, lay close and parallel to the marginal fold. Similar villous covered folds of the chorion, many of which were one foot and upwards in length, traversed the chorion in various parts of its extent; frequently they ran parallel to each other, and two or more were sometimes close together, but at other times they were separated by intervals of 3, 4, or 5 inches. Usually the greatest projection of one of these folds was about 2 inches, though sometimes it reached 3, or even 4, but towards their extremities they gradually subsided to the general plane of the chorion.

Besides these elongated folds, villous covered folds of another form, but not so numerous, projected from the surface of the chorion. They were triangular in shape, flattened on their surfaces, and with the apex and lateral borders free. A very characteristic specimen is represented in Plate VII. fig. 18. Its margin of attachment was 4 inches, whilst its diameter from this margin to the free apex was $5\frac{1}{2}$ inches. On the elongated and triangular folds, but more especially the former, the villi were thickly studded, but on the intermediate surface of the chorion they were more sparingly distributed, and were for the most part collected on minute and ridge-like elevations, which intersected each other, and presented an irregularly reticulated appearance. The membrane between these slight ridges was comparatively smooth and transparent.

The mucous surface of the uterus in the mother must have possessed numerous depressions of considerable length and depth, into which the elongated and triangular folds of the chorion would have fitted. In the special aggregation of the villi on these folds an approach to the cotyledonary type of the placenta found in the Ruminantia may be traced.

The opposite surface of the chorion was in relation to the placental blood-vessels, some of which were of considerable size; one, which was measured, had a circumference of $2\frac{3}{4}$ inches. Where the folds on the villous surface were well marked an artery coursed along and gave off many collateral branches, which entered into the fold to end in the villi. The chorionic vessels were surrounded by a delicate connective tissue, which was loosely connected with the attached surface of the amnion. Lying in this connective tissue were numerous opaque, white, slender threads, which differed from the small arteries in not being tortuous, and in giving off their branches at very acute angles. These threads had to the naked eye the appearance of fine nerves. When examined with the microscope, they were found to possess an external investment of well-marked connective tissue, which surrounded lines of an irregular granular or semi-globular substance which looked like the disintegrated medullary sheaths of nerve fibres. The free surface of the amnion was smooth and glistening.

Although nothing definite seems to be known of the period of gestation of

the Finners, yet from the length of the calf, and the well-developed state of its parts, it is probable that the whale was at or about her full time. Dr SCORESBY considered that February and March were the months in which the *Balœna mysticetus* gave birth to her young,* but ESCHRICHT and REINHARDT, from observation made at the Danish whaling factories, think that it is between the end of March and the beginning of May.† If my supposition be correct that the whale was at her full time, then this *Balœnoptera* gives birth to its young in the later autumn months, and not, like the Greenland Right whale, in the spring of the year.

This view of the period of parturition of the great Finner is strengthened by evidence which I have received from another source. In the month of October 1869, a large female Finner, which, from information that I have obtained,‡ I believe to be of the same species as the Longniddry whale, was found in a creek about a quarter of a mile to the south of Hamna Voe, Northmaven, Shetland. It was dead, and floating by its side was a dead calf, which was well developed, and bore to the mother about the same proportion as the Longniddry animals did to each other. Alongside the calf was a quantity of membranes, which, from the statements of the fishermen, were evidently the fœtal membranes. The calf had obviously been born about the time of the death of the mother, and had apparently reached the full period. The maternal mammary glands were so charged with milk that a quantity was observed to flow out through the teats.

The capture of two of these whales in the pregnant condition within so short a period in arms of the sea, lends support to the statement which has more than once been made, that the Finners resort to bays and creeks for the purpose of bringing forth their young.

Skin and Blubber.—The colour of the skin has already been described; a few words may, however, be said on its structure. The epidermis readily peeled off the cutis when decomposition had begun. It was distinctly laminated and thicker than the human cuticle. On the belly, for example, it measured $\frac{1}{5}$th of an inch, and on no part indeed of the surface of the trunk was it seen to possess a greater thickness. In this respect it contrasts strongly with the skin of the *Balœna mysticetus*, which in some places has the cuticle one inch thick.§ The superficial layer could be peeled off as a thin horny stratum,

* Account of the Arctic Regions. I., 470.

† Memoir translated for the Ray Society, p. 10.

‡ I am indebted for information regarding this whale in part to Mr J. WALKER of Maryfield House, Bressay, and in part to Mr COUGHTREY. The latter gentleman has just returned from a visit to the Shetland Isles, and when there not only collected at my request various interesting facts about this animal, but also procured for me a number of its bones.

§ Dr KNOX (Catalogue of Anatomical Preparations of the Whale, Edinburgh, 1838) points out the thinness of the cuticle in the species of the great northern Rorqual which he dissected; nowhere, he says, did it exceed $\frac{3}{16}$ths of an inch. He compares it with the *B. mysticetus*, and shows how in the one there are conjoined thin cuticle and short baleen, in the other thick cuticle and long baleen.

which, when dried, had the appearance of gold-beater's skin. The deeper layers contained more pigment than the superficial, and in those parts of the skin where the colour was most marked the deep surface of the cuticle had a rich black hue. When the epidermis was removed, rows of distinct elongated papillæ were seen; and in vertical sections through the entire skin the relations of these papillæ to the cuticle* could be studied (Plate VIII. fig. 29). The papillæ were filiform, and as a rule simple, but in some cases two or even three papillæ arose by a common stem, which then subdivided. They were comparatively long, and their apices reached therefore much nearer to the surface of the skin than might have been supposed. In some of the sections I observed distinctly the small arteries of the cutis giving off branches which entered the bases of the papillæ and extended for some distance within them.

The blubber or subcutaneous tissue was composed of adipose tissue, for the oil was contained in well-defined fat cells. These cells were supported by bands of connective tissue, many of which possessed considerable breadth and strength. Blood-vessels passed in some numbers through the blubber, partly for its nutrition, and partly for the nutrition of the integuments on its surface. The blubber varied considerably in thickness in different parts of the subcutaneous tissue of the adolescent animal. On the sides and upper edge of the lower jaw, it was from 10 to 16 inches. Beneath the ear-slit 8 inches; along the ventral surface about 4 inches. On the top of the beak and cranium 8, 12, and even 15 inches. In front of the dorsal fin from 12 to 16 inches, and behind this projection from 14 to 21 inches, which seemed to be the maximum thickness. The thickness of the blubber at the tip of the caudal spine was 3 inches, and at the symphysis of the lower jaw $4\frac{1}{2}$ inches, so that the length of the skeleton was within $7\frac{1}{2}$ inches that of the entire animal. In the fœtus the blubber was very imperfectly formed; and the thickness of the subcutaneous tissue was almost uniform, on the belly not exceeding one inch; and on the back scarcely reaching two inches.

In the older animal, an enormous mass of soft fat was situated within, and formed a sort of fatty lining for the abdominal cavity. From the heat which was disengaged by the putrefaction of the carcase, this fat was liquefied, and ran in streams on to the shingle, where it again solidified, and was collected into barrels.

Mr Tait estimated that he had obtained from the blubber ten tons of oil, and from the inside fat six tons, so that the pecuniary value of the whale from

* In the Anatomical Museum of the University of Edinburgh are several specimens (161 to 164) prepared upwards of twenty years ago by the late Professor Goodsir, one from the *B. mysticetus*, three from a "Rorqual," probably the *Balænoptera musculus*, which give most illustrative views of the filiform papillæ of those animals.

these sources alone was very considerable. He has also furnished me with an estimate of the weight of the other portions of the carcase, from which we may make an approximation to the weight of the entire animal. The flesh and viscera 36 tons, the baleen and "gum" 10 cwt., the skeleton 9 tons 10 cwt., the blood and refuse 12 tons, which, with the oil and fat, make in all 74 tons as an estimate of the weight of the entire animal.

Mammary Gland.—The position of the nipple has already been described in the section on the external form of the animal. The gland itself was exposed by the removal of the blubber on one side of, and for several feet anterior to, the genital fissure. It formed an elongated body, and measured between 7 and 8 feet in its antero-posterior diameter, and of this extensive mass only 8 inches lay behind the nipple. Its greatest transverse diameter was 20 inches, and the thickness of the gland substance, which surrounded any part of the great central duct, was more than 6 inches. Its broadest part was in the region of the nipple, gradually tapering off to its anterior end. Its colour was a rich red; and its subdivision into lobules by bands of connective tissue could be readily recognised by the naked eye. When cut into, it was seen to be traversed along its entire length by a central duct, which increased in size as it passed from before backwards, and at the base of the nipple formed an enormous sinus, the transverse diameter of which was about 8 inches. Numerous large ducts, into many of which the closed hand could be passed for some distance, opened out of this central duct, and extended into the various parts of the gland. The transverse diameter of one of these ducts was $5\frac{1}{2}$ inches. The orifices of the primary ducts opening into the great central canal, and those of the smaller ducts which opened into the primary, were mostly oblique in their direction, and a well-marked fold of the mucous membrane bounded one-third, and sometimes more, of the aperture. As a general rule, the direction of these ducts was towards the nipple, but some ran in the opposite direction. The mucous membrane which lined the ducts and central canal was firm, and marked on its free surface by a characteristic ridge and furrow-like appearance (Plate VI. fig. 11). These ridges were parallel to the long axis of the duct. At the base of the nipple the great sinus-like dilatation of the central canal suddenly narrowed to the duct within the nipple, which was not larger than would admit the middle finger or thumb. The lobules of the gland were polygonal in shape and variable in size; some of the larger ones had a diameter of $\frac{1}{5}$th inch. Sections through the lobules examined microscopically gave very illustrative views of the structure of a compound racemose gland. The clusters of acini or gland vesicles, with their contained secreting cells, could be seen with great distinctness, and the arrangement of the interlobular connective tissue could be traced.

In the subcutaneous tissue around the nipple and at its base, numerous plexiform vessels were seen, so that it is probable that erectile tissue exists

in this locality. Lying outside the mammary gland was a muscle which, by its contraction, would aid in expelling the milk along the ducts, and through the orifice of the nipple.

The size of the secondary ducts of this gland, and the dilatation of the single central duct into a great reservoir for the collection of the milk, have obviously special reference to the aquatic mode of life of an animal which suckles its young. For, as JOHN HUNTER long ago pointed out,* the mode in which these animals give suck is very inconvenient for respiration, as if the mother were to turn round so as to elevate the nipple to the surface then her nares would be under water; whilst, if the mother remains in her normal position, then the nose of the calf must be under water, and the time of sucking can only be between each respiration. It is necessary, therefore, that the gland should be so constructed as to allow of a considerable accumulation of milk in the ducts, which may be readily drawn off by the calf in the intervals between the respiratory acts.

Baleen.—When the lower jaw was removed by cutting through the massive fibrous columns, which connected the condyles of this bone to the base of the skull, and when the occipito-atloid joint was disarticulated, the skull was turned over on its dorsum, and a complete view of the roof of the mouth, and of the baleen *in situ* was obtained. Extending from behind forward in the mesial plane of the palate was the great central crest or keel, which was much broader and more prominent posteriorly than anteriorly, and was covered on its free surface by a black mucous membrane. Immediately on each side of the base of the keel the palate was covered by a smooth and almost flat, black mucous membrane, and external to this again was the lateral series, or wreath, of deep black baleen plates with their inferior free edges fringed with black setæ.

The wreaths of baleen plates on the two sides converged as they passed forwards, and at the anterior part of the mouth they became continuous with each other, as is the rule indeed in the Finner whales.† Posteriorly, where they lay close to the entrance into the gullet, they were separated by a considerable interval; though here also they inclined inwards to the base of the great mesial palatal keel. The inner edge of each wreath had a curved outline with the concavity towards the mesial keel. The outer edge was convex, and in its curvature closely corresponded to that of the margin of the beak itself. This border was bounded by a raised fold, the coronary or wreath-band (*Horn-Kranzband* of ROSENTHAL), and was situated one foot within the outer edge of the beak. Where the two wreaths became continuous in front, the junction took place seven inches within the tip of the beak.

* Structure and Economy of Whales. *Phil. Trans.* 1787.

† ESCHRICHT and REINHARDT. I have also seen this in two specimens of *Balænoptera rostrata*.

Each wreath was estimated to contain about 370 rows of plates,* and each row consisted of several plates or blades or bristles. The rows lay transversely and parallel, though not in straight lines, for they were somewhat curved, the convexity forwards, the concavity backwards, and the smaller inner subsidiary plates were arranged in an oblique manner. Intervals varying from one half to three-eighths of an inch existed between the rows in different parts of the series. The transverse and vertical diameters of the plates varied considerably, not only in different parts of the wreath, but also in each row, for the plates diminished in size from the outer to the inner edge of the row. At the anterior part of the mouth they were little more than coarse black bristles, and the free part of these projected in some only half an inch, in others one inch and a half, into the cavity of the mouth. Extending backwards along the outer or labial part of the wreath the baleen increased in size, at first being somewhat elongated narrow plates, and then increasing in their transverse diameter at their base of attachment, until they assumed the unequally four-sided form, with its surfaces directed forwards and backwards, of the blade represented in Plate VI. fig. 12, which may be regarded as a very characteristic specimen of one of the large plates of this *Balænoptera*. The dimensions of this plate were as follows. The transverse diameter along its base of attachment 1 foot 6 inches; vertical diameter, inclusive of the part imbedded in the intermediate substance, along outer free border, 2 feet $9\frac{1}{2}$ inches, along inner free border 8 inches. Length along the border fringed with setæ 3 feet 3 inches. The setæ varied in their length, some measuring as much as 17 inches. On the surface of the plate numerous longitudinal parallel lines, which at its inferior edge became continuous with the setæ, were observed. Transverse rings, which sometimes were close together, at others were separated by wider intervals, passed from one surface to the other around the outer and inner free edges of the plate. A plate of this form and of somewhat similar dimensions formed the external or labial blade of each transverse row in by far the greater portion of the wreath.

Internal to this large plate the baleen, though of the same black colour, was elongated and narrow; the blades possessed the form represented in Plate VI. fig. 13, their transverse diameter was not more than $\frac{8}{10}$ths of an inch, and their vertical diameter, inclusive of the part imbedded in the intermediate substance, was in some 7, in others 6, in others 5 and 4 inches. Each of these narrow subsidiary plates had an uniform breadth, and the setæ, which were often more than 6 inches long, arose not from the sides, but only from

* Although the rows of plates were counted without difficulty in the greater part of the wreath, yet at the posterior end, and at the front, of the mouth the exact enumeration was attended with considerable difficulty, owing to the bristle-like baleen being arranged in less definite rows than were the blades of this substance.

the free end. Whilst the setæ generally had the same deep black colour as the plates, in some cases they had more of a deep soot brown tint. The baleen at the inner end of each transverse row consisted, not of plates, but of short bristles, similar to those already referred to at the anterior end of the series. As the vertical diameter of the plates and the length of the setæ were so much greater in the outer than in the inner parts of each transverse row, it followed that the lower bristle-fringed aspect of each wreath arched, from without, obliquely upwards and inwards, so that the roof of the mouth presented a considerable concavity from side to side.

The plates were all imbedded at their attached palatal borders in a dense semi-elastic, slate-coloured material, the intermediate substance or "gum" of the whaling seamen. This substance varied in its thickness from its attached to its free surface to from 1 to 4 inches in different parts of the wreath, and was thinner along the outer and inner borders than in the intermediate portions. It was continuous, along the inner border of the wreath, with the cuticle investing the palatal mucous membrane, and along the outer border, with the coronary or wreath-band already referred to. The free surface possessed an irregular softened, water-worn appearance.

After decomposition had begun the baleen and intermediate substance, intimately connected together, could be readily peeled off the surface of mucous membrane from which they grew, and their mode of growth and structure could be examined.

All anatomists know, who have studied the structure of whalebone, that, when a blade is carefully detached from the surface of the palate, the edge or base of attachment is cleft along the line of its transverse diameter into two laminæ. If these laminæ be drawn asunder numerous holes are seen at the bottom of the cleft, which open into tubes or canals that traverse the substance of the plate in the vertical direction. It has been pointed out by Eschricht and Reinhardt, that in the short baleen plates of the Rorquals or fin whales the length of these tubes is comparatively greater than in the much longer plates of the Greenland Right whale. In the Longniddry whale, the deep black colour of the baleen made the plates so opaque, that the existence of the tubes could only be surmised by the longitudinal markings visible on a surface examination, and it was not until after sections were made in the vertical or transverse direction, that the tubes could be distinctly seen.

In vertical sections the tubes were cut longitudinally, and could be followed for some distance (Plate VII. fig. 19). They contained a delicate, brownish-yellow substance, which could be easily drawn out of the tube. In the part of the plate which surrounded the tubes numerous black pigment granules were distributed in such a manner as to give to the section the appearance of longitudinal striation.

Transverse sections of the plates, examined with low magnifying powers, were, however, the more instructive (fig. 20). The number and size of the tubes was by no means uniform in the different parts of the same transverse plane. Sometimes a single comparatively large tube was alone met with; at others two, or even a larger number, occupied the antero-posterior diameter, and in this case the tubes were considerably smaller. The soft brownish-yellow contents were readily recognised, and in many of the sections this substance was seen to be perforated with holes, which looked like transversely-divided small blood-vessels.

The solid portion of the plate was spotted with black pigment, and distinctly striated. The striæ ran in two different directions, and indicated a laminated arrangement. One set of striæ or lamellæ surrounded, in a concentric manner, the individual tubes, and in their arrangement might be compared with the lamellæ surrounding the Haversian canals in a transverse section of bone. They may be called the tubular lamellæ; and the tube, its contents, and the lamellæ surrounding it, might be termed a tubular system. The other lamellæ were situated on the peripheral part of the plate, and formed a sort of envelope enclosing the tubular system of lamellæ. These may be called the peripheral or cortical lamellæ; and they formed that part of the plate which has been called the cortical layer or "enamel" of the whalebone. When examined with higher powers of the microscope, the lamellæ were seen to be composed of elongated and flattened cells, each containing a distinct nucleus, and more or less black pigment (fig. 21). These cells were obviously peculiarly modified epithelial cells. The intervals between the outermost lamellæ of adjacent tubular systems were filled up by cells, which presented less of a flattened and more of a fusiform or rod shape; these cells, though interstitial in their position, were apparently continuous with the cells of the cortical layer.

Transverse sections through the setæ displayed in each a central tube or canal, surrounded by the usual arrangement of concentric tubular lamellæ (fig. 22). The tube within the seta contained a similar soft brownish material to that found in the tubes within the blade itself. Each seta represented, therefore, a single tubular system.

When vertical sections through the intermediate substance, in which the bases of the plates were imbedded, were examined with low powers of the microscope, the deep surface attached to the palate was seen to be much more highly charged with pigment than the more superficial parts, and so regularly was it disposed, that it might almost be described as a special pigmentary layer of the structure. The deep surface had an uniform rich black colour, and was perforated by numerous apertures, which in the vertical sections were seen to lead into clefts which passed some distance into the intermediate substance (fig. 23). The black pigmentary layer was prolonged along the walls of these

clefts. Under higher powers of the microscope, the intermediate substance was seen to consist of flattened cells, epithelial in character (fig. 24), and the black pigmentary layer was due to a special accumulation of pigmentary granules in the deepest cells of this substance. This layer may be considered therefore as comparable to the *Rete Malpighii* of the human cuticle.

The intermediate substance was intimately united to the laminæ formed by the cleavage of each plate at its base; so close indeed was this union that it was impossible to separate them from each other without injury to the latter. It not unfrequently happened, in tearing away the substance from between the plates, that a portion of the cortical layer of the adjacent part of the plate peeled off along with it. A distinct horizontal lamination was seen on the surface of vertical sections made through the intermediate substance.

In my further researches into the structure of the baleen, I have derived considerable assistance from the examination which I made of the baleen of a recently killed, lesser Pike whale, *B. rostrata*, about 18 feet long, which was captured at Burntisland in September last. In this animal the plates were for the most part white, or yellowish-white, but, when quite fresh, a distinct pink or rosy colour was seen, more especially in that part of the blade which lay within and next to the intermediate substance. Some days after death the pink or rosy colour became converted into purple.

When a fresh blade was examined in a good light, the pink colour was found to be not on the surface, but within the substance of the plate, and arranged in regular lines, which ran parallel to each other from the attached border to the free border fringed with setæ, and in many cases it extended even into and along the latter. When a pocket lens was used in the examination, the colour was seen to be due to a red fluid contained in the numerous tubes which traversed the plate in its vertical diameter. Sometimes the fluid formed an unbroken column of one, two, or three inches in length; but at others the column was much subdivided, and reminded one of the appearance presented by a broken-up column of mercury in a barometer tube when out of repair. In some of the tubes, more especially those situated near the outer and inner edges of the plate, the red fluid was either absent, or extended only a short distance down the tube. Many of these tubes appeared as if subdivided by little septa passing across their canals, not unlike the arrangement one has seen in the medullary part of a hair. When the baleen plate was cut across transversely, and forcibly squeezed between the finger and thumb, the red fluid oozed out of the divided tubes, and when collected on a glass slide was examined microscopically. Under a high power numerous circular, disk-shaped, non-nucleated corpuscles, which possessed the optical characters of blood corpuscles, were found in it (fig. 25), and along with these were three-sided prismatic crystals, probably the triple phosphate, and numerous actively moving

vibriones. It was clear, therefore, that the pink tint of the baleen in the Pike whale was due to the blood* situated in the tubes which traversed its substance in the vertical direction.

I am not aware that any explanation has previously been given of the cause of the pink colour of the baleen in the lesser Pike whale. Indeed many writers seem to have paid but scanty attention in their descriptions to the existence of this tint.

Both in the Longniddry and the Pike whales the surface of the palate, from which the baleen grew, possessed numerous transversely elongated folds of the palatal mucous membrane (the pulp-blades of Eschricht and Reinhardt), corresponding in their arrangement and transverse diameter to the different sizes of the baleen plates in the various transverse rows, and fitting into their cleft basal edges (fig. 26). The largest of these folds in the former animal projected as much as $\frac{7}{10}$ths of an inch from the general palatal surface. The free lower edge of each fold was fringed with multitudes of well-marked elongated filiform papillæ, which fitted into and indeed filled up the tubes in the plates and setæ already described. These may be called the tubular papillæ. If great care was taken in stripping off the plates, the papillæ could be drawn out of the tubes, and in fig. 26 a view of a number of these structures from the interior of the tubes of a plate of the Longniddry whale is given. The tubular papillæ varied in length in this preparation, some being 3 inches long, whilst others were considerably shorter; but none of these papillæ represented the full length of the tubes they originally occupied, as they always broke short in the act of removal. They varied also in thickness, in correspondence with differences in the bore of the tubes; and they were thicker at their attached than free extremities.

Folds and papillæ of this character have been described with more or less fulness of detail by Hunter, Ravin,† Rosenthal,‡ Knox,§ Owen,‖ Eschricht and Reinhardt,¶ Flower,** and Malm,†† in connection with the baleen in the different whales which they have examined; and in the Anatomical Museum of the University of Edinburgh are several specimens, prepared, I believe, in the year 1843, by the late Professor Goodsir, which furnish very illustrative views of the folds and larger papillæ of the baleen plates. They have been regarded as the nidus, matrices or pulps, from, and in connection with, which the specially

* As confirmatory evidence of this fluid being blood, I may state that I requested my friend, Dr Arthur Gamgee, to apply the chemical test for blood. He found that the fluid gave with guaiacum and peroxyde of hydrogen the characteristic greenish-blue colour of hæmoglobin.

† Ann. des Sc. Naturelles, 2 Sér. t. v.

‡ Abhand. der Akad. der Wissensch. zu Berlin, 1829, p. 127. § Catalogue, *op. cit.*

‖ Odontography, p. 312. ¶ Ray Society's Translation, *op. cit.*

** Proc. Zool. Soc., 1865, Nov. 28.

†† Monographie Illustrée du Baleinoptère, Stockholm, 1867.

modified, horny, epithelial cells of the baleen plates were developed. The vascularity of the folds and of the papillæ has also been recognised by these anatomists, but no exact description of the arrangement of the vessels has as yet been given.

The fresh condition of the baleen in the *B. rostrata* led me to think that it might be possible to inject its papillæ, and to obtain a more complete view of the arrangement of their vessels than had yet been described. I accordingly carefully detached the entire palatal mucous membrane, with its baleen wreaths, from the upper jaw; and after introducing injecting pipes into several of the palatine arteries, I succeeded with the aid of my assistant, Mr STIRLING, whose skill as a minute injector is so well known, in injecting the vessels of the baleen. But before proceeding to describe their arrangement, it will be necessary to speak of two other groups of papillæ, which appear hitherto to have been overlooked by anatomists. When the surface of the palatal mucous membrane, situated between the bases of the transverse folds, was examined with a pocket lens, it was found to be studded with short papillæ, which fitted into clefts similar to those already described (fig. 23), as extending into the intermediate substance from its deep attached surface. These papillæ we will call intermediate. Similarly, when the sides of the transverse folds were also examined with a pocket lens, they were seen to give origin to numerous minute papillæ, which passed into minute apertures in the inner wall of each of the laminæ, produced by the cleavage of the baleen plate at its base. These laminæ were continuous with the cortical layer of the plate to which they belonged, and their papillæ may be called peripheral or cortical.

In the injected preparations, the following appearances were seen in vertical sections (fig. 27). The palatal mucous membrane was highly vascular, and the principal vessels ran parallel to the horizontal plane. They gave origin to smaller vessels, which were distributed to the three groups of papillæ. Those which passed to the intermediate papillæ, occupying the spaces in the attached surface of the intermediate substance, did not enter the transverse folds or pulp blades; they were very slender, but formed distinct loops (fig. 27). The vessels for the other papillæ entered the transverse folds. Those destined for the peripheral or cortical papillæ formed a well-defined superficial network of small vessels, which gave off, at intervals, capillaries which entered these papillæ, and formed loops in the usual manner. The vessels for the elongated, filiform, tubular papillæ were considerably larger. As a rule, two entered the base of each papilla, and extended along its axis into the tube. These vessels preserved their size for a very considerable distance down the tube, and occasionally anastomosed. They were easily recognised by the naked eye, both in vertical and transverse sections of the plates and setæ; and it was in them that the blood was contained which conferred on the baleen of *B. rostrata* its characteristic pink markings.

When the papillæ were carefully extracted from the tubes, and examined with high powers of the microscope, they were seen to consist of a delicate, wavy, connective tissue, the filaments of which lay parallel to the long axis of the papilla. The nucleated corpuscles of the connective tissue were distinctly recognised after the papilla had soaked some time in glycerine. On the free surface of the papillæ a very distinct layer of flattened polygonal cells, with their borders in close contact with each other, like epithelial cells on a free surface, was met with. These cells were soft and delicate, and were evidently the youngest layer of epithelial cells lying next the papillæ, which had not yet undergone the horny transformation. In some of the papillæ I saw, more especially at their broader attached ends, elongated fibres, having a double contour, which I believe to have been medullated nerve fibres.

The baleen of the fœtus of the Longniddry whale possessed some features of interest, to which I may now refer. Only the wreath, which was met with early in the dissection of the mother, was preserved, for the opposite wreath, which had also been shed from the palatal surface, was lost in the course of the dissection. The wreath was 4 feet long, and $3\frac{1}{2}$ inches in its greatest transverse diameter. The anterior end had been broken away, and lost, but the posterior end was flattened, and terminated in an obtuse angle. Notwithstanding the loss of its most anterior portion, as many as 335 transverse rows were counted in the wreath, and they were slightly curved with the convexity forwards. Owing to the comparative thinness of the intermediate substance, the interval between any two adjacent transverse rows was not more than $\frac{1}{10}$th of an inch. Here, as in the adult, the outer or labial plate in each transverse row was by far the largest; indeed, those internal to it were little more than short bristles in the fœtus. In the greater part of the wreath seven, eight, or sometimes nine plates or bristles were counted in each transverse row. Towards the anterior end only five were counted; but posteriorly, where the external plate, like those internal to it, consisted of a mere bristle,—the number of bristles in the row had increased to about thirty, and at the same time the rows increased very materially in their obliquity. Quite at the posterior end the bristles were so feeble as scarcely to be visible.

In the fœtal wreath I recognised not only the transverse arrangement just described, but also a distinct antero-posterior or longitudinal arrangement of the baleen. The outer longitudinal row was formed by the series of large plates, whilst those internal consisted of the bristle-like baleen. The number of longitudinal rows varied, however, in different parts of the wreath, where variations occurred in the number of elements in the transverse rows.

The baleen had not the rich black colour so characteristic of the plates in the older animal. The plates were dark grey, intermingled with black. The setæ were light grey, and the intermediate substance had a similar tint. The

substance bore a greater proportionate thickness to the vertical diameter of the entire plate than in the older animal. In one of the largest unequally four-sided plates, whilst the greatest vertical diameter was $2\frac{1}{2}$ inches, the padding at its thickest part was 1·6 inch; but at the inner and outer border of the plate it was only 0·8 inch. The greatest transverse diameter of this plate at its attached border was 2·3 inches. The longest setæ projecting from the free lower border of the plate measured $1\frac{1}{2}$ inch. The fœtal baleen plates had a distinctly fibrous appearance, and, from the thinness of the cortex, could be readily torn along the vertical diameter into numerous fine parallel horny fibres, which in each plate corresponded in number to the setæ, and consisted of the tubular systems, with their contained papillæ. The openings into the tubes were visible in the cleft between the basal laminæ of attachment of the plate. No transverse rings, such as have been described in the older animal, were seen on the surface of the fœtal baleen plates, a circumstance which adds to the probability of the view entertained by Eschricht and Reinhardt, that the rings indicate a periodical change in the formation of the cortical part of the blade. When transverse sections through a plate were examined microscopically, the tubes, the tubular lamellæ, and the peripheral lamellæ were seen, but on a much smaller scale; the peripheral lamellæ especially being thinner, and not so distinct as in the older animal, so that the entire plate was consequently much thinner. The intermediate substance readily tore up in the vertical direction, and the torn surface was longitudinally streaked, to all appearance, in conformity with the development of its epidermal cells, in connection with the basal papillæ. Numerous black pigment granules were scattered through both the plates and intermediate substance.

The surface of the palatal mucous membrane, from which the fœtal baleen had been shed, presented folds or pulp-blades, which, in their general plan, though with some modifications in form, agreed with those already described on the palate of the mother. A series of transversely elongated folds corresponded to, and fitted within, the clefts at the bases of attachment of the large external plates of the transverse rows. Internal to these, owing to the baleen having so much more of a bristle than a plate-like form, the elevations of the mucous surface were not transversely elongated, but had more the shape of sub-conical papillæ (Plate VI. fig. 15). The corresponding surface of the baleen wreath, instead of presenting a series of transversely, elongated, short clefts, as in the mother, possessed polygonal pits, mostly of a regular hexagonal form (fig. 16), into which these sub-conical papillæ fitted. Towards the anterior part of the palate, the folds were so faintly marked as to be recognised with difficulty.

As the violence which had occasioned the rupture of the uterus, and the displacement of the fœtus, had in all probability, also, been the cause of the separation of the baleen wreaths from the palate, the elongated tubular papillæ

had, for the most part, been torn off the folds of the palatal mucous membrane, and were included within the tubes of the baleen plates. In some localities, however, some of these papillæ still retained their proper attachments to the folds; and they presented an appearance which reminded one, though on a smaller scale, of that which has already been described and figured in the older animal.

John Hunter, in his account of the mode of growth of whalebone, pointed out very clearly that a baleen plate is formed upon a thin broad process of a vascular substance, which fits into the hollow at the base of the plate, and that the first part of the growth takes place on the inside of the hollow. He was also of opinion that the cortical layer of the baleen, and the intermediate substance arose on the surface of the vascular membrane, and were continuous with each other. He showed their relations to hair, nails, and other epithelial structures, and stated that the free surface of the intermediate substance softens like the old cuticle of the sole of the foot when steeped in water. Eschricht and Reinhardt described epidermic cells as continually forming, not only on the pulp-blades, but on the smooth intervals of the palatal membrane between the blades, the cells of the latter constituting the comparatively soft intermediate substance, whilst those of the former hardened into the horn-like material of the baleen plate. The medullary or tubular portion of the plate formed on the free lower edge of the pulp-blade, and on the numerous, soft, elongated, filamentous papillæ which fringe it, whilst the cortical layer of the baleen plate formed on the free lateral surfaces, and inner and outer edges of the pulp-blade, which it ensheaths.

This description by the distinguished Scandinavian anatomists is, I believe, as far as it goes, perfectly accurate; but the observations which have just been recorded enable me to supplement it with some new and important particulars. For, in addition to the elongated, filamentous, vascular papillæ of the tubes, two other sets of vascular papillæ have been observed—a cortical and an intermediate—each of which has its appropriate epithelial investment. Hence we may now state, that each of the three great groups of epithelial cells found in the baleen wreath takes its rise from, and constitutes the epithelial investment of, a distinct set of vascular papillæ. The cells which form the tubular lamellæ, are the cornified epithelium of the filamentous tubular papillæ: those which form the peripheral or cortical lamellæ are the cornified epithelium of the cortical papillæ; whilst the softer intermediate substance consists of the epithelial cells, which invest the sides and summit of the intermediate papillæ.

Many anatomists, in discussing the characters and morphological position which whalebone occupies amongst the textures, have compared it with the teeth, and have regarded it as a special modification of the dental tissue, springing from the surface of the palate. But it seems to me, that a more exact

comparison may be found in the well-marked vascular folds of mucous membrane, covered by epithelium, which lie transversely across the palate in the Ruminantia. In the giraffe, for example, these folds are very strong, and they are, moreover, fringed along the free edge with well-defined papillæ, which are also covered with an epithelium. If we were to suppose these papillæ considerably elongated, their epithelium cornified, and the whole series of papillæ, springing from any single fold, bound together by a cortical, cornified, epithelial layer, we should then have an arrangement of parts closely corresponding in structure to that of a plate of whalebone. But the Balænoidea are not the only placental mammals in which a cornified epithelium is developed in connection with papillary growths from the surface of the buccal mucous membrane. For, as is well known, in the Carnivora, the papillæ on the dorsum of the tongue are invested with a horny epithelium arranged in the form of retroverted spinules.

I am also of opinion that we must assign to the baleen a more important function than that of the mere hair sieve or filter, with which it is most usually compared. For structurally it is much more highly organised than hair. It is highly vascular, and, I believe, also nervous, and can therefore play the part of a whole series of tactile organs, by means of which the animal would be enabled to estimate the amount and character of the food which it receives into the cavity of the mouth.

As Geoffrey St Hilaire* and Robert Knox† had discovered rudiments of the teeth in the gum of the very young fœtus of the *Balæna mysticetus*, and as Eschricht‡ had also observed them in the fœtal stage both of *Megaptera* and *Balænoptera*, I removed the gum from the edges of both the upper and lower jaws, with the view of examining if the rudiments of these organs still existed in the almost fully developed fœtus of the Longniddry Finner. I found in connection with the periosteal surface of each gum a well-defined band, which corresponded precisely with the margin of the jaw, and which received a number of arteries coming through foramina in the bones. This band, from its position, was obviously the part in which the teeth, if present, ought to have been found. A careful examination, however, both of the band and of the tissue on each side, failed to discover the smallest rudiment of a tooth. Hence it follows that in the Balænoidea not only do the teeth not pierce the gum, but all trace even of their rudiments disappear before the termination of fœtal life.

Alimentary Organs.—Owing to the wide sweep of the lower jaw, the cavity of the mouth was of great size, and the space included between the two halves of the lower jaw reminded one of a huge barge; indeed it was no uncommon

* Annales du Museum. Vol. x. p. 364.

† Catalogue, *op. cit.* p. 22. Knox's preparations are in the Anatomical Museum of the University of Edinburgh.

‡ Die Nordischen Wallthiere, 1848.

thing, when the animal was lying on the beach, to see a number of persons standing within the left mandible on the dorsum of the tongue as it was exposed by the falling over of the beak to the right side. The roof of the mouth was formed by the palate and baleen plates; its sides corresponded to the great antero-posterior cleft between the upper and lower jaws; its floor was formed by the dorsum of the tongue included within the two halves of the mandible. The dorsum of the tongue was almost flat near the front of the mouth, but somewhat further back it presented a considerable elevation, which arose like a hillock, and fitted within the concavity of the roof of the mouth between the opposite wreaths of the baleen. The tongue was very compressible and elastic. The mucous membrane on its surface was of a dark slate colour, and was at once reflected from the dorsum at the tip and sides of the tongue to the inner surface of the lower jaw, so that the tongue was tied to that bone, and obviously could not be protruded from the mouth. The surface of the mucous membrane was firm and tough; it was marked by ridges and furrows, which, for the most part, were placed longitudinally, though some extended in the transverse direction.

The mouth rapidly narrowed towards the posterior buccal orifice. In the adolescent animal the diameter of this orifice was 10 inches. The mucous membrane was, in this locality, brownish-yellow in colour, and spotted with patches of brown and black pigment. Numerous rounded or somewhat oblique orifices opened on its free surface. These communicated with pits, the largest of which formed depressions $\frac{3}{8}$ths of an inch deep in the mucous membrane, big enough to admit peas; these were obviously the mouths of gland follicles. The upper boundary of the orifice was formed by the soft palate, which was about an inch and a half thick, and distinct muscular fibres entered into its construction.

In the fœtus the posterior buccal orifice was much more constricted, for its diameter was only 2 inches. It was bounded above by a broad, well-defined velum, which extended backwards for $6\frac{1}{2}$ inches, and possessed a broad attachment on each side to the pharyngeal wall, sending also a posterior pillar backwards on each side as far as a line opposite the arytenoid cartilages (Plate VIII. fig. 30). The greatest breadth of the soft palate was 7 inches. Its position was almost horizontal; mucous membrane covered its upper and lower surfaces and posterior border, and from the latter no uvula projected. The absence of an uvula in the lesser Pike Whale had previously been noticed by Drs Carte and Macalister.* Owing to the breadth of the attachment laterally of the velum, the passage from the mouth to the pharynx was much more in the form of a canal, which may be termed the bucco-pharyngeal canal, than a simple opening. This canal gradually

* Philosophical Transactions, 1868, p. 232.

widened in its backward passage, for whilst only the tips of the four fingers could be introduced into its buccal orifice, the fist could be readily passed through it from the pharyngeal end. The mucous membrane surrounding the buccal orifice and lining the bucco-pharyngeal canal, was spotted with pigment, and with pits, such as have been described in the same region in the older animal. The mucous membrane was also thrown into faint transverse folds, which corresponded in their direction with the fibres of the well defined palato-glossus muscle. The part of the pharynx situated immediately above the velum was greatly dilated, and measured 24 inches in circumference. It constituted the nasal subdivision of the pharyngeal chamber. The antero-posterior diameter of the pharynx from the posterior border of the soft palate to the commencement of the œsophagus was 9 inches. In its general form it was funnel shaped; for whilst the transverse diameter just behind the attachment of the velum was $7\frac{1}{2}$ inches, it rapidly narrowed behind, where it joined the œsophagus to a tube, $1\frac{3}{4}$ inch in diameter.

When the interior of the pharynx was more completely exposed by a mesial longitudinal incision, not only could the posterior buccal orifice be more clearly seen, but the relations of the superior laryngeal opening were exposed (Plate VIII. fig. 31). In front of this opening was the elongated, tongue-like flexible epiglottis, which projected forward and upward. It was invested by mucous membrane, and from its anterior surface a well-defined hyo-epiglottidean fold of mucous membrane passed forwards to the body of the hyoid. Projecting from the middle of its posterior surface was a vertical rounded elevation, which obviously corresponded to the "cushion" described by Czermak on the back of the human epiglottis, and which, doubtless, like that cushion, plays an important part in the closure of the laryngeal orifice during deglutition. From each side of the epiglottis a strong aryteno-epiglottidean fold of mucous membrane passed backwards to the lappet-like processes of mucous membrane which invested the horns of the arytenoid cartilages, which formed the posterior boundary of the orifice. These lappets were separated by a median cleft. No hood-like fold of mucous membrane, such as Drs Carte and Macalister have described in *B. rostrata*, as affording protection to the orifice of the larynx during deglutition, existed in this animal. The superior orifice of the larynx was large enough in the fœtus to admit both fists at the same time.

The muscular wall of the pharynx was formed of the constrictors, the fibres of which passed from below upwards, to be attached to the superior mesial raphé of the pharynx. The fibres of at least two pairs of constrictor muscles, arising from the hyoid bone and thyroid cartilage, were distinctly recognised. The muscular coat of the œsophagus was comparatively thin, and presented the longitudinal and circular arrangement.

Numerous glands existed in the submucous coat of the pharynx. The position of many of these was marked, more especially on its lateral and anterior

walls, by crypt-like depressions in the mucous membrane, some of which were large enough to admit a kidney bean, others not bigger than a pea (figs. 30, 31). These crypts were collected into groups, the best marked of which were situated close to the junction of the anterior border of the soft palate with the anterior wall of the pharynx.

In studying the method by which this and other whalebone whales collect their food in their huge mouths prior to deglutition, it should be kept in mind that they are not provided either with teeth, or with a protrusible tongue by which to grasp the prey. It is probable that when in search of food, the animal swims about with its mouth wide open, until a sufficient quantity of food is collected on the dorsum of the tongue, in the space between the two halves of the mandible, prior to being swallowed.

Though the depression of the lower jaw in the act of opening the mouth is doubtless due to muscular action, yet, when once open, the jaw may, I believe, remain depressed without the continued action of muscles. The huge fibrous columns, which pass, one on each side, from the base of the skull to the condyles of the lower jaw, so suspend that bone, as to support it without the need of calling into action any muscle; for it was observed, as the animal was floating at high water, that the lower jaw was open, and swayed gently to and fro with the movements of the waves. To draw the jaw back prior to deglutition, the temporal and other elevator muscles must be called into action; and, as the jaw is raised, the tongue is pressed upwards against the lower edges of the baleen, and the water contained in the cavity of the mouth is forcibly squeezed out between the rows of plates. The food retained in the mouth by the sieve-like fringes of the baleen, is then forced back through the bucco-pharyngeal canal, doubtless by the action of the tongue, into the pharynx, when the constrictors grasp it and force it back into the œsophagus. Here the soft palate acts as a valve to prevent its passage upwards to the nose, and the superior laryngeal orifice is closed by the co-aptation of the epiglottis, arytenoid cartilages, and aryteno-epiglottidean folds of mucous membrane, so that it cannot enter the larynx. In these respects, therefore, the mechanical arrangements for preventing the passage of the food into the respiratory passages, closely remind one of the structures found in the corresponding locality in the human subject. As it is also important that water should not pass from the mouth into the pharynx whilst the animal is collecting its food; and as the respiratory process is performed, not by the mouth but by the nose, the contraction of the fibres of the palato-glossal sphincter would effectually close up the bucco-pharyngeal canal at the time when these processes were going on.

The stomach was so injured in various places by the men engaged in flensing the animal, that little more was ascertained in connection with it, than that it was subdivided into at least four compartments, which communicated with each

other by valvular orifices. One of these valves was secured, and reminded one on a large scale of the human pyloric valve, or of the valve I described and figured some time ago* at the end of the fifth compartment of the stomach of *Globiocephalus svineval.* The stomach was to all appearance empty.

An omentum was in connection with the stomach, which, when stretched out, was big enough, in the mother, to cover the floor of a large room. It was made up of fibres, composed of connective tissue, which crossed each other so as to form a most elegant lace-work pattern, with distinct perforations in the meshes of the net. Blood-vessels were seen in the larger bands of fibrous tissue which traversed the net. Scarcely any adipose tissue was found in it, which is the more remarkable, when we remember the enormous quantity of fat situated as a sort of inner padding for the wall of the abdominal cavity.

The intestinal canal was of great length, and by far the longer part of its extent consisted of huge coils, of which as many as fifteen were counted, though it is probable that a greater number existed. The hinder end of the gut, as it passed backward to the anus, was almost straight, and about 20 feet long. No accurate measurement of the length of the intestine could be taken, but it was estimated at about 80 feet, for the various coils, as soon as they were removed from the abdomen, were carted away to the manure heap. The circumference of the tube was not uniform throughout, varying in different localities from 20 to 30 inches. Extending along the border of the intestine at the line of reflection of the mesentery was a very remarkable looking tube with thick walls, which exhibited an alternating series of dilatations and constrictions, which gave it a beaded appearance (Plate VIII. fig. 32, *m*). This tube gave off a number of branches, which ramified in the subserous areolar coat of the gut, and formed there a complex anastomosing network. Along with this moniliform tube was a large vein (*v*), and accompanying it was a nerve (*n*), considerably larger than the human pneumo-gastric, which gave off branches to the wall of the intestine. This nerve was obviously a large offshoot of the sympathetic. The intestine possessed a distinct peritoneal coat (*p*), which rested on the subserous areolar tissue. The muscular coat was thick, and the longitudinal and circular arrangement of fibres was strongly marked. A distinct submucous coat was present. The mucous membrane was brownish-yellow, and thrown into strong valvulæ conniventes, some of which extended two-thirds, others half round the canal of the gut. The largest valvulæ projected at least one inch into the canal. Numbers of parasites were attached to the surface of the mucous membrane. I have not as yet had time properly to examine them, but they are in general appearance like the *Echinorynchus brevicollis* which MALM found in the intestine of the *Balænoptera* which he examined.

* Journal of Anatomy and Physiology. Vol ii. p. 73.

I can say nothing more of the anatomy of the liver than that it was subdivided into two lobes. The pancreas was not recognised in the course of the dissection.

Organs of Circulation.—My observations on the arrangement of the heart and blood-vessels were made chiefly on the fœtus, but in several points were supplemented by a reference to the corresponding structures in the adolescent animal. The heart was contained in a well-formed pericardium. In the mother it was of enormous size; and in the fœtus it was considerably larger than the heart of an ox. It presented externally the usual arrangement of grooves, which marked its subdivision into four chambers, and in these grooves the coronary vessels ramified.

In the fœtus the right auricle, when opened into, showed a smooth inner surface for the most part, but the anterior wall and the interior of the appendix had well-defined fleshy columns projecting into the cavity. In the intervals between these columns the auricular wall was dilated, and formed a number of pouch-like recesses. The superior cava, large enough to admit five extended digits, opened into the anterior and external part of the cavity, and had no valve at the orifice. The inferior cava, large enough to admit the fist, opened into the posterior and external part of the auricle. No trace of an Eustachian valve was seen at its mouth. The mouth of the coronary sinus readily admitted the tips of three fingers, and opened between the inferior cava and the auriculo-ventricular orifice, and was also without a valve.

In the interauricular septum an almost circular foramen readily admitting five extended digits was situated. Surrounding this opening, and attached to its edge, a loose, membranous, annular fold, formed by a duplication of the endocardium was seen. When put on the stretch it projected into the auricle, and the projecting border was free and pierced with large fenestræ. Although this fold was situated in the right auricle, when I opened into that cavity, yet it could without difficulty be passed through the foramen into the left auricle. At the attached border, again, the membrane was almost entire, and most perfect in its anterior, external, and posterior portions, where the depth from the attached to the free borders was 4 inches. This membranous fold was situated at some distance from the mouth of the inferior cava, so that it could not be regarded as the Eustachian valve in the sense in which it is customary to use that term. From its position it would, however, seem to have served some purpose in connection with the flow of blood from one auricle to the other during fœtal life; but it is possible that, by growth both in thickness and surface, it might, after the birth of the creature, have closed up the orifice and completed the auricular septum. I think it probable that the structure described by Dr Knox (*Catalogue*, p. 24), in the heart of a fœtal *mysticetus*, as "a membranous sac, the size of a full-sized thimble, presenting at the bottom a delicate reticulated net-work, and projecting into the left auricle," was similar to the annular fold observed in this fœtal *Balænoptera*.

A well-defined tricuspid valve was placed at the right auriculo ventricular orifice. The cusps had the same relative position as in the human heart, and the arrangement of the carneæ columnæ, musculi papillares, and chordæ tendineæ was closely similar. In the older whale one of the cusps measured 10 inches in width at its base, and the depth from base to apex was $8\frac{1}{2}$ inches. Some of the chordæ tendineæ were 12 inches long, and the girth of one of the largest of these, where it arose from a papillary muscle, was $2\frac{1}{2}$ inches. As it subdivided before it joined the cusp, the size of its branches was very materially smaller.

The pulmonary artery arose from a distinct conus arteriosus. It ran forwards and to the left, and divided into two branches for the right and left lungs. Its left branch gave origin in the fœtus to a widely patent ductus arteriosus, which joined the arch of the aorta immediately behind a spot opposite the origin of the left subclavian artery (Plate VII., *x*).

In the mother a strong, fibrous, rounded cord, 5 inches long, passed between the pulmonary artery and aorta in the place of the ductus arteriosus. Its circumference at its aortic attachment was about 6 inches, and it was somewhat thicker at its opposite extremity. When transversely divided it was seen to be distinctly laminated, and extending along its axis was a canal readily admitting a large sized catheter. This canal widened out into a funnel-shaped passage at its two extremities, where it opened into the aorta and pulmonary arteries. Hence, even in the adolescent animal the arterial duct was patent, though, from the small size of the canal, any intermixture of blood which might have occurred would be so small as not to affect the characters of the enormous volume of that fluid contained in the arterial system. It is interesting also to note that Knox found a pervious ductus arteriosus in the great Rorqual which he examined, and Dr Murie observed it in an adult *Balœnoptera musculus*.* The trunk of the pulmonary artery in the mother was 3 feet 7 inches in internal circumference, and its coat, which was distinctly laminated, varied in thickness from $1\frac{1}{4}$ inch to $\frac{3}{4}$ths of an inch. The internal circumference of one of the primary branches was 1 foot 5 inches, the thickness of its coat $\frac{1}{8}$th of an inch. The internal circumference of one of the pulmonary veins was 19 inches.

The left auricle, in the mother, had much thicker walls and a redder colour than the right; but in both, the appendages were large, and the fleshy columns within them, and on the adjacent part of the auricular wall, were enormously developed, one of the largest measuring 5 inches by 3, another 6 inches by 2, and so on. The pouch-like dilatations, already referred to in the description of the fœtal auricle, between these columns readily admitted one or both fists. From the mode in which the columns intersected each other, they and the pouches gave to this part of the auricle quite a cavernous character. The

* Proc. Zool. Soc., Feb. 14, 1865.

muscular wall at the bottom of some of the pouches was often so thin as to be translucent when held up to the light. Many of these pouches were situated parallel and close to the auriculo-ventricular groove.

The left ventricle had thicker walls than the right, and, in connection with its walls and auricular opening, carneæ columnæ, musculi papillares, chordæ tendineæ, and a bicuspid valve were seen.

The arch of the aorta in the mother rivalled in its calibre one of the main pipes for the supply of water to a district of a large city. The internal circumference of its ascending part was 3 feet 2 inches, whilst its coat varied in thickness from $1\frac{1}{4}$ to $1\frac{1}{2}$ inch. The coat was distinctly laminated, of a yellow colour, and very elastic. A well-defined inner membrane lined it and the other parts of the arterial and venous systems. The external circumference of the aorta in the fœtus was 10 inches. It then dilated prior to giving origin to the great branches of the arch, and immediately beyond these vessels it diminished materially in size as it became the posterior thoracic aorta. The external circumference of the innominate artery in the mother was 1 foot 9 inches.

The aorta arched to the left over the root of the lung (Plate VII. fig. 28). A pair of coronary arteries (*a*) arose from the commencement of its ascending part, one passing on each side of the root of the pulmonary artery. Each coronary immediately subdivided into three branches, the largest of which turned round its own margin of the heart in the auriculo-ventricular groove, and supplied the corresponding auricle and ventricle. The second branch of the right coronary entered the wall of the right auricle; the third turned round the root of the pulmonary artery. The second branch of the left coronary artery descended in the anterior inter-ventricular groove; the third passed to the substance of the left ventricle. In the mother each coronary artery was as large as the posterior aorta of an ox.

From the anterior surface of the transverse part of the arch three large branches arose, the brachio-cephalic, left carotid, and left subclavian (*b*, *c*, *d*). The right branch, by far the largest, was the arteria innominata or brachio-cephalic (*a*). Five inches (in the fœtus) from its origin it bifurcated into a right common carotid (*e*) and right subclavian (*f*). The right subclavian gave off, one inch from its origin, a large branch, the right posterior thoracic (*g*), which was traced into the great thoracic rete mirabile. One inch and a-half further on the subclavian bifurcated into the axillary (*h*) and internal mammary (*i*) arteries, the latter of which was somewhat the larger of the two, and supplied the inferior wall of the chest. The axillary passed in front of the first rib, immediately above the scalenus anticus muscle; but before doing so it gave off a considerable branch which ran forwards along the side of the neck. The axillary was traced into the flipper, and, in the dissection of the fore-arm,

branches of this artery were found lying, along with distinct nerves, in connection with the flexor and extensor muscles of the digits.

The right common carotid (*e*) ran forwards for 6 inches and then bifurcated. The branches should, I think, be regarded as the cervico-facial (*k*) and internal carotid (*l*) arteries. The cervico-facial, much the larger, passed to the deeper parts of the head, but gave off also a large branch to the face. The internal carotid was torn across; but branches arose from it which passed to a rete mirabile in the neck. The state of the parts prevented me from tracing out to their termination the branches of the right common carotid artery.

The second branch of the transverse part of the arch was apparently a left common carotid artery (*c*). It gave off a small branch to the side of the neck, and then bifurcated 7 inches from its origin. The larger branch of bifurcation was the cervico-facial (*m*), which divided into many branches for the head and face. The smaller branch was apparently the internal carotid (*n*).

The third branch of the transverse part of the arch was the left subclavian artery (*d*). It gave off a large branch, the left posterior thoracic (*o*), to the great thoracic rete, and then divided into the left axillary (*p*) and internal mammary (*q*) arteries. The rete mirabile was not confined to the thoracic cavity, but extended upwards into the neck, and prolongations were traced through the intervertebral foramina into the spinal canal. The large foramina at the roots of the transverse processes of the cervical vertebræ were also occupied by considerable masses of this highly vascular network.

The posterior thoracic aorta ran backwards, and gave off the series of intercostal arteries. It then entered the abdomen and supplied the various viscera; but the distribution of its branches, owing to the injured state of the viscera, could not be followed out. It was noticed that in the fœtus the hepatic artery was as large as the human common iliac. The abdominal aorta was prolonged backwards as the great caudal artery, which was protected by the series of arches formed by the chevron bones. From the caudal artery, opposite the body of each vertebra in the fœtus, two branches, which entered the middle of its ventral surface, were traced into the ossifying centrum of each vertebra.

It may not be out of place to refer to what has been stated as to the arrangement of the great arteries, which arise from the transverse part of the arch in some of the other Cetacea, where the vessels have been carefully dissected. Knox,* Eschricht,† and Carte and Macalister‡ have all pointed out that in the *Balænoptera rostrata*, three great arteries, the brachio-cephalic, left carotid, and left subclavian arise from the transverse part of the arch. Knox also states that, in his great Rorqual, the arrangement of the vessels arising from the arch

* Catalogue, p. 18.

† Die Nordischen Wallthiere, p. 104.

‡ Philosophical Transactions, 1867, p. 245.

followed closely that of man; and he refers to brachio-cephalic, left carotid, and left subclavian arteries; and MALM observed a similar disposition in his *Balænoptera*. It seems, therefore, that these great arteries have a similar mode of origin in different species of Finners. In *Delphinus* and *Globiocephalus*, however, the great arteries arise in the form of two brachio-cephalic arteries, and the left posterior thoracic arises usually quite independently; but as I have on former occasions * described these arrangements, I need not in this place enter into any further details.

It will be necessary now to give an account of the very remarkable moniliform tube, which I have referred to in the description of the intestine of the adolescent animal. It was found along the entire length of the mesenteric attachment of the gut, and extended back along the rectum. It exhibited an alternating series of dilatations and constrictions, which varied in their dimensions in different parts (Plate VIII. figs. 32, 33). The dilatations were sometimes globular, at others ovoid in form, and in some cases were flattened on their surfaces. The largest measured as much as 1 foot 6 inches in transverse external circumference, whilst the smallest were only 8 or 9 inches. When the dilatations were ovoid the elongation was mostly in the direction of the long axis of the tube, in which direction the circumference of the dilatation was therefore somewhat greater. The constrictions also varied in size, the smallest being about 4 inches in external circumference, the largest 1 or 2 inches more. The tube possessed very strong and dense walls, which varied in thickness in different parts. In the larger dilatations the thickness was as much as $1\frac{1}{4}$ inch, but in the smaller not more than $\frac{1}{4}$ inch. The walls were white, tough, and very resisting. Examined microscopically, the tissue which composed them was seen to be chiefly the white fibrous, but mingled with it were elastic fibres. The inner surface of the wall presented a corrugated appearance, owing to the presence of a number of permanent, circular folds, wrinkles or ridges, which passed quite around the inner surface of the tube (fig. 33). In many places these folds were situated close together; but elsewhere they were separated by intervals in which the inner wall of the tube was comparatively smooth. These ridges were in part formed of a folding of the lining membrane of the tube, and in part of the fibrous tissue of the wall. Some of the largest of these folds projected as much as 1 inch, or even more, into the lumen of the tube, and as this projection was carried all round the inner wall, the lumen was necessarily much constricted in these localities, and in the smaller divisions the bore was sometimes reduced to a hole in the middle of the fold less than 1 inch in diameter, whilst on each side of it the tube might perhaps dilate into a space 2, 3, or more inches in its diameter. Hence the dilated and constricted

* British and Foreign Medico-Chirurgical Review, October 1862, p. 479, and Journal of Anatomy and Physiology. Vol. ii. p. 66.

character of the tube visible externally was an index of important internal arrangements. Numerous branches, into which an injection was readily thrown, arose from the moniliform tube, and passed directly into the subserous coat of the gut. They were about the size, at their origin, of the human brachial artery, and ran straight and parallel to each other for some distance, giving off but few branches; then they altered their direction, and formed, by anastomosing, a series of arches from which numerous branches arose, which ran towards the free margin of the intestine, again to anastomose, and give rise to still smaller branches, which penetrated the muscular and mucous coats of the gut.

In connection with the exterior of some of the dilatations of the moniliform tube a peculiar structure was dissected. It consisted of a number of closely crowded lacunæ, varying in size from a pea to a walnut (Plate VIII. fig. 34), separated more or less perfectly from each other by septa formed of a delicate smooth membrane, similar to that which also lined the interior of the lacunæ. The arrangement to some extent corresponded with that of a multilocular cyst, the loculi of which communicated with each other. In one spot a distinct tube, the size of the stem of a common tobacco pipe, was seen to open into a group of these lacunæ. In some places, more or less elongated, and sometimes ovoid, bodies of a dark brown colour, were situated immediately beneath the delicate semi-transparent lining membrane. These bodies had the appearance of lymphatic glands, and this view of their structure was confirmed by a microscopic examination, for, notwithstanding that the specimen had been for sometime in spirits of wine, distinct, pale, circular, lymphoid corpuscles were seen to enter in large numbers into the structure of these bodies. I did not succeed in tracing out any connection between this lacunary system and the wall of the intestine, though it is possible that the small tube, just referred to, may have proceeded from or to the wall of the gut.

It was unfortunate that in the portions of intestine, with the moniliform tube attached, which were sent over to the Anatomical Museum for examination, none of the expanded part of the mesentery had been preserved. I was consequently unable to trace the branches which proceeded from the proximal surface of this tube to their origin. I have little doubt, however, but that they were derived from the mesenteric artery.

In the fœtus the intestine was, as a rule, so softened by putrefaction that it could not be preserved. One or two coils were, however, somewhat more perfect, and after being hardened in strong spirits of wine, I was enabled to effect a partial examination.

The mesenteric artery did not possess that complete series of arterial arcades, which we are familiar with in man. It branched comparatively seldom, and its branches ran towards the border of the intestine. Those which arose nearest the gut did not enter directly the intestinal wall, but passed to an

elongated structure, which lay parallel to and next its mesenteric border. This structure occupied the position of the moniliform tube in the parent whale, but did not possess its beaded appearance. Indications, in places, of a tube traversing its long axis were seen; but in the greater part of its extent it was apparently subdivided into a large number of minute spaces, so that the surface of section had quite a cavernous aspect. From this structure numerous fine branches arose, which passed into the subserous coat of the intestine, to be distributed there like the branches of the moniliform tube in the parent animal. It would seem, therefore, that in the fœtus the moniliform tube is not developed in the same precise manner as in the adolescent whale, but that a series of inter-communicating spaces occupy the position in which it subsequently appears. The formation of the moniliform tube, out of this lacunary system, would be occasioned by a great increase in size of those lacunæ which lie in the same longitudinal series, and by the great hypertrophy of their originally delicate walls. It is probable that the lacunæ described on the surface of some parts of the dilated tube in the parent (fig. 34), represented in it the original condition of the mesenteric lacunary system of the fœtus.

In the Cetacea, important arrangements, in connection with the vascular system, exist in various parts of the body for the purpose of modifying and equalising the force of the blood current. The great cervico-thoracic rete mirabile, with its numerous offshoots into the spinal canal and cranial cavity, is the arrangement which has been most carefully studied by different anatomists. But in considering the function of this network, it is not sufficient to regard it as merely a reservoir, or huge sponge, which contributes, by its complex ramifications, to produce an enormously extended area for the reception of the blood, when the whale dives to a great depth from the surface of the ocean. It serves, I believe, the purpose, by minutely subdividing the arterial stream, of distributing and equalising the force of the blood current before it reaches those delicate organs the brain and spinal cord. It may be regarded, therefore, as the teleological equivalent of the arteries in the human pia mater, of the circle of Willis, of the tortuosities in the vertebral and internal carotid arteries, and of the rete mirabile in connection with the intra-cranial arteries in ruminants and in the pig.

With what, then, are we to associate the large moniliform tube in the mesentery of this whale? From its beaded character it might at the first glance be supposed to belong to the lymphatic system; but the careful consideration of the distribution of its branches, and of its relations to the mesenteric arteries, have led me to the conclusion that it is a remarkable modification of the mesenteric arterial system, which serves the same office, for the intestine, that the rete mirabile does for the brain and spinal cord.

The great size of the aorta and of the trunk of the mesenteric artery, the

paucity of the system of arterial arcades, the proximity of the intestine to the aorta, the pressure, from the elastic recoil of the arterial wall, of the enormous column of blood in the aorta, would seem to render some mechanical arrangements necessary, by means of which that pressure may be distributed and regulated before the blood enters the slender arteries within the wall of the intestine.

The structure of the moniliform tube admirably adapts it for this purpose. The blood flows through it on its way to the intestinal arteries, and is diffused into the numerous dilatations or bays which bulge out from its sides. The transverse inflexible folds on its inner wall diminish at intervals the lumen of the tube, and where they project so far as to leave but a narrow aperture in the axis of the tube, they act as strictures in retarding the flow of the current. At the same time their circular arrangement enables them to act as internal girders, and to strengthen the walls so as to prevent over distension of the tube.*

I have already referred to the analogy between the rete mirabile in the cetacea, and the network in connection with the intra-cranial arteries in the pig. I may now allude to a modification which the pig exhibits in the arrangement of its mesenteric arterial system. The arteries subdivide in the middle of the mesentery, and form there a compact network—a rete mirabile—from which numerous small arteries radiate outwards to the intestine.† These radiating vessels closely correspond in appearance to those which I have described as arising from the moniliform tube in the Longniddry whale. The Cetacea, therefore, present affinities to the Pachydermata, not only in the diffused character of the placenta, but in the possession of closely allied modifications of the cerebral and intestinal arterial systems.

The presence of a moniliform tube, in connection with the intestine, does not seem to have been previously recognised in the Cetacea by anatomists.

The superior vena cava was formed by the junction of the two innominate veins, on the right of the ascending aorta. Each innominate vein began at the root of the neck in the form of a dilated sinus, into which the veins from the neck, flipper and inner wall of the chest opened. The inferior cava received a number of hepatic veins before it pierced the diaphragm. The umbilical vein was 27 inches long in the fœtus in its course from the umbilicus to the liver.

The portal vein in the fœtus had a diameter of 3 inches before it entered

* My colleague, the Professor of Engineering, Professor Fleeming Jenkin, to whom I pointed out the structure of this tube, concurs in the opinion of its function expressed in the text.

† The mesenteric rete in the pig has long been known to anatomists—see Barclay on the Arteries, Edinburgh, 1812; T. J. Aitki in Reports of Edinburgh Meeting of British Association, 1834, p. 681; Owen, Comparative Anatomy of Vertebrates, vol. iii.; Gurlt, Anatomie der Haussaugethiere, Berlin, 1860. The complexity of the rete in the pig is due to the plexiform arrangement of both the mesenteric vein and artery.

the liver. In the coil of intestine from the adolescent animal, from which fig. 32 was taken, a vein larger than the human inferior cava, ran close and parallel to the great moniliform artery of the intestine, and received numerous veins, the rootlets of which took their origin within the coats of the gut. In the fœtus a vein lay along with the artery in the expanded part of the mesentery.

At the upper part of the cavity of the thorax in the fœtus, close to the apex of the pericardium, a well-defined, though small, thymus gland was found. It was subdivided into two lobes, each of which was brown in colour, thin, and flattened in form, and 5 inches in length by $4\frac{3}{4}$ inches in its greatest breadth. The lobes were subdivided into distinct lobules by intermediate connective tissue, and they received numerous blood-vessels. In proportion to the size of the animal the gland was obviously smaller than might have been anticipated. The thyroid gland, supra-renal capsules and spleen were not recognised during the dissection.

Organs of Respiration.—When the cavity of the thorax was opened into, by the removal of the inferior wall, the lungs were exposed. In the fœtus each lung was an elongated, flattened organ 2 feet 8 inches in length. It was invested by a distinct and smooth pleura, and was not subdivided into lobes by fissures. A similar absence of fissures and lobes I have also seen in the lung of *B. rostrata.* The pulmonary artery, veins, and bronchus entered its substance through the hilum on its mediastinal surface. When the lung was removed and washed with a jet of water, the softened pulmonary substance broke down, and was washed away, and the arrangement of the intra-pulmonic part of the bronchus could be seen. This tube, as a rule, branched in a dichotomous manner, though collateral offsets sometimes proceeded from it. It was accompanied by the pulmonary and bronchial arteries, and by bronchial nerves of some size.

The cartilaginous framework was much more perfect than in the human bronchus. The tube was hooped with cartilaginous, spirally arranged, ring-like plates; in the larger tubes usually not more than once and a-half, but in the smaller tubes a greater number of times (fig. 35). Sometimes in these latter the cartilage formed perfect rings, and both in them and in the larger tubes the cartilaginous plates not unfrequently bifurcated. The branching of the plates was always well-seen at the angle of the bifurcation of the tubes. The plates were invested by a well-defined perichondrium. The hoop-like and spiral coils of these cartilaginous plates have an important office in connection with the respiratory process in this animal. They not only aid in keeping the tubes open, but, by their elasticity, aid in the recoil of the lung during the great expiratory effort which the whale makes in the act of blowing. The diameter of the right bronchus in the fœtus was 2 inches, that of the left $2\frac{1}{2}$ inches; in the mother one of the bronchi was 7 inches in diameter.

Three inches in the fœtus, above the place of bifurcation of the trachea, that tube gave off a supplementary bronchus, $1\frac{1}{2}$ inch in diameter, to the right lung, which seems to be, as SANDIFORT and ESCHRICHT have pointed out, the usual arrangement in the cetacea, the Greenland right whale being excepted.* The trachea had three, somewhat irregularly formed, cartilaginous hoops immediately above the bifurcation; but from the highest of these up to the arytenoid cartilages, a distance of $6\frac{1}{2}$ inches, which corresponded to two somewhat subdivided tracheal rings, and to the interval between the separated inferior borders and plate-like processes of the cricoid, the cartilage was deficient inferiorly, and the ventral wall of the wind-pipe was formed of fibrous membrane. The mucous membrane of the trachea, more especially on the anterior wall, was marked by numerous fine reticulated folds, the chief of which ran parallel to the long axis of the tube. The diameter of the trachea was about 5 inches.

The cartilaginous framework of the larynx consisted of a thyroid, a cricoid, a pair of arytenoid cartilages, and an epiglottis. The form, arrangement, and connections of these cartilages were examined in the fœtus (Plate VIII., figs. 36, 37, 38).

The thyroid cartilage consisted of a median and two lateral portions. It was a comparatively thin plate, and possessed two surfaces, a superior and inferior, which were flattened, and two margins, an anterior and a posterior. The median part, tongue-like in form, was bifid at its hinder border, and projected for some distance backward; a deep notch marked its superior border; from this notch, to the end of the forks of the tongue-like part, the diameter was $4\frac{1}{2}$ inches. The lateral portion curved outwards, and was then prolonged backwards, as the elongated and somewhat rounded posterior cornu to be articulated by a moveable joint with the outer surface of the cricoid. The anterior cornu was continuous with the anterior border of the cartilage; it was short and rudimentary. The cartilage was connected to the body and great cornua of the hyoid bone by a strong membrane, and a pair of thyro-hyoid muscles passed between them.

The cricoid cartilage was an incomplete ring; superiorly, it formed a thick mass of cartilage 7 inches in its antero-posterior diameter. Its surfaces were curved, and it turned round the sides of the wind-pipe towards its ventral aspect, and ended in the greater part of its extent in a free rounded border. From the hinder part of this inferior border, however, five plates, similar in form to the cartilaginous hoops of the trachea, arose and turned round the side of the larynx to the ventral surface; but the plates from opposite sides did not meet in the mesial line. An interval, varying in its transverse diameter

* Die Nordischen Wallthiere, p. 148, Ray Society's translation of Memoir on Greenland Whale, p. 103.

from 3 to 4 inches, separated the opposite inferior margins from each other. It was filled up by a strong fibrous membrane, which was continuous laterally with the perichondrial investment of the cricoid and its plate-like offshoots, anteriorly with the perichondrium investing the posterior horns of the two arytenoid cartilages, and posteriorly with the membrane which filled up the interval between the ventral borders of the first two cartilages of the trachea. This membrane, which may be called the inferior crico-tracheal membrane, was of great importance as completing the wall of the windpipe on its ventral aspect. The posterior margin of the cricoid was comparatively narrow; the anterior margin possessed at each lateral angle a broad surface for articulation with the body of the arytenoid cartilage, distinct capsular and synovial membranes connected the two cartilages.

Each arytenoid cartilage, irregular in form, consisted of a body and two cornua. The body formed a thick plate of cartilage. The anterior cornu curved upwards and forwards into the lappet-like fold of mucous membrane behind the superior laryngeal opening. The posterior cornu curved backwards and inwards within the area enclosed by the sides of the cricoid; it almost reached the mesial plane, where a transverse fibrous ligament connected it by the tip to its fellow. The two posterior horns formed an imperfect hoop, invested by the mucous membrane of the larynx, which was prolonged directly backwards and downwards to form the mucous lining of the laryngeal sac. The free rounded border of the cricoid was connected to the posterior cornu of the arytenoid by the inferior crico-tracheal membrane. A crico-thyroid muscle existed also on each side, and muscular fibres were seen to occupy the position of the crico-arytenoidei postici and arytenoideus.

The epiglottis contained a bar of yellow fibro-cartilage, which passed backwards along the axis of the entire structure, to be attached to the superior surface of the middle portion of the thyroid cartilage. In the older animal, from which it had been removed without much injury,* the entire organ measured 25 inches in length, whilst its breadth at the base was about 10 inches; it was thick and massive, and rounded in form at its free end. The fibro-cartilage was covered by mucous membrane, which was prolonged backward as the aryteno-epiglottidean folds, and forward as the hyo-epiglottidean fold. When this membrane was removed from the hinder surface of the epiglottis and its arytenoid connecting folds, a strong aryteno-epiglottideus muscle was exposed, which curved upwards and inwards, decussating with its fellow in the substance of the epiglottis, and obviously was arranged to act as a

* The other laryngeal cartilages were so much injured during their removal from the adolescent whale, that I was unable to examine them satisfactorily. I may, however, refer to their great size and thickness, more especially of the cricoid and body of the arytenoid. The cartilage was traversed in various directions by very distinct vascular canals.

powerful sphincter for closing the glottis during deglutition. A deeper set of fibres of the same muscle was exposed by the removal of the thyro-hyoid membrane.

There were no true vocal cords passing from the thyroid to the arytenoid cartilages, or laryngeal ventricles, but a slight fold of the mucous membrane, extended obliquely in the antero-posterior direction within the aperture of the glottis, on each side, a short distance below the free edge of the aryteno-epiglottidean folds. These might, perhaps, be regarded as rudimentary false vocal cords.

One of the most interesting structures connected with the larynx was the great laryngeal pouch or cul-de-sac. It was 10 inches in length in the fœtus, and extended backward from the thyroid cartilage, in close relation to the ventral surface of the inferior crico-tracheal membrane, to within 2 inches from the bifurcation of the trachea. Its outer wall was formed by a powerful muscle, which arose from the superior surface of the median tongue and adjacent lateral plate of the thyroid, from the inferior free border of the cricoid, and from the body of the arytenoid. The fibres were arranged in transverse rings around the walls of the pouch, and they formed a thick mass at its posterior end. The pouch was lined by a mucous membrane, which was continuous with the general mucous lining of the larynx, by extending upwards on the inner surface of the bodies of the arytenoid cartilages, and by passing round the free border of the hoop formed by their posterior horns. The mouths of numerous large crypts opened on the surface of this membrane.

Owing to the peculiar arrangement of the arytenoid cartilages and the presence of this pouch, the laryngeal chamber might be regarded as subdivided into three compartments. The supero-anterior which formed the glottis proper, was bounded by the epiglottis, the aryteno-epiglottidean folds, and the anterior horns and bodies of the arytenoid cartilages with their investing and intermediate mucous membrane. The posterior was bounded above and to the sides by the cricoid cartilage, in front by the two posterior horns of the arytenoids, which ran obliquely from above backwards and downwards; through the fissure between these horns it communicated with the glottis, whilst behind it was continuous with the canal of the trachea. The inferior was the laryngeal pouch above described, which communicated directly and freely with the glottis at the base of the epiglottis, but with the posterior chamber through the fissure between the arytenoid horns. This pouch is often regarded as occasioned by a deficiency in the ventral part of the ring of the cricoid cartilage. But from the description of the arrangement of these parts, and from the figure 37, it will be seen that although this plate of cartilage is defective, yet that the ring is completed ventrally by the strong inferior crico-tracheal fibrous membrane, beneath which the pouch is situated. The laryngeal sac is rather to be regarded

as a diverticular prolongation of the mucous membrane between the thyroid and cricoid cartilages, accompanied by an imperfect development of the crico-thyroid membrane.

The air entering the lungs during inspiration would have to pass from the glottis into the trachea through the fissure between the posterior horns of the arytenoids; but the air, entering the laryngeal pouch, would pass into it below these two horns. The close approximation of these cornua would aid in the closure of the glottis, and in the retention of the air in the lungs when the whale has dived to a depth from the surface.

The presence of a laryngeal pouch or sac in the *B. rostrata*, which he dissected, had not escaped the acute observation of JOHN HUNTER. In his account of that animal he says,* "The arytenoid cartilage on each side sends down a process, which passes on the inside of the cricoid, being attached to a bag which is formed below (behind) the thyroid, and before (below) the cricoid; these processes cross the cavity of the larynx obliquely, making the passage at the upper part a groove between them." SANDIFORT† then pointed out and described its arrangements in two fœtuses of *Balœna mysticetus*. KNOX observed it‡ not only in *B. rostrata*, and *B. mysticetus*, but in his great northern Rorqual, and he specially directed attention to the mode in which it was supported by the posterior horns of the arytenoid cartilages. ESCHRICHT has also recognised this sac not only in the fœtus of *B. rostrata*, but in that of the *Megaptera longimana*;§ and REINHARDT and he have anew carefully described it in the Greenland Right Whale. A description, with several figures, of the sac in *B. rostrata* has recently been published by Messrs CARTE and MACALISTER.‖

Of these authors the last named alone discuss the probable use of this very remarkable pouch. They consider, that by the contraction of its muscular walls, it may expel the contained air so as to augment the power of, and to sustain the expiratory current. They suggest that it might aid in the production or modulation of sound, if the whales possessed such a faculty, but think that the size of its aperture, and the absence of all constricting bands, or apparatus, militate against that view of its use.

The powerful muscular wall of the sac is unquestionably for the purpose of permitting the contraction of the wall on the contents, and as the pouch communicates above directly with the glottis, a rapid contraction of the investing muscle would aid the expiratory act. But there is another purpose to which this sac may be applied. It may serve the office of a reservoir in which a

* Structure and Economy of Whales.
† Nieuwe Verhand. van Wetensch. te Amsterdam, 1831.
‡ Catalogue, pp. 11, 17, 23.
§ Die Nordischen Wallthiere, p. 103, c. s.
‖ Op. cit., p. 236, c. s.

quantity of oxygenated air may be stored up to be made use of when the animal remains for some time below the surface, by permitting an interchange, by diffusion, to take place between the pure air in it and the carbonised air within the lungs.

It has been customary to consider, that because the *Balænoidea* have no vocal cords, therefore they have no voice, and cannot produce sound.* But although they do not possess a pair of elastic bands, extending horizontally across the larynx between the arytenoid and thyroid cartilages, such as we see in the mammalia generally, yet in the posterior horns of their arytenoid cartilages, united by the transverse ligament, they possess a pair of structures which can be approximated or divaricated, and by the vibration of which, as the air passes between them, into or out of the lungs, sounds may very probably be elicited.† Their vibration would, without doubt, be assisted by their close relation to the air-filled laryngeal pouch.

The nares consisted of two vertical passages, separated by a cartilaginous septum, which opened superiorly on the dorsum of the head by the external apertures or blow-holes, whilst by their deeper orifices they communicated with the nasal part of the pharynx. When looked at from below (fig. 39), the mucous membrane was seen to be pitted with the mouths of numerous gland follicles, and to cover the surface of an oval fibro-cartilage which formed a considerable convexity in the outer and anterior wall of the passage, and in contact with the outer surface of which was a muscle. When the external orifice was widely opened, a fold, occasioned by the position of a large postero-external cartilage, fitted into a corresponding depression on the antero-external wall (fig. 40). A muscle, apparently a dilator, lay beneath the skin to the outer side of the aperture, and was attached to the cartilage at its postero-external angle. It is clear that the nostrils can be readily and widely opened, and also forcibly and completely closed, during the respiratory movements, so as to retain the air within the windpipe and lungs when the animal dives below the surface of the water.

Genito-urinary Organs.—In fig. 9, the form and relation of the penis in the fœtus are represented. As all that portion of the organ in front of the crescentic folds was invested by integument, the penis in this animal seemed in its flaccid state, not to be altogether retracted within a sheath, but to be in part

* Dr Martyn, in a paper published in the Proc. Roy. Soc., London, 1857, ascribed the supposed absence of the voice in the cetacea to the absence of a thyroid gland; but as I pointed out in a memoir published, in 1860, in the Transactions of this Society, a thyroid gland exists both in Phocæna and Delphinus.

† Whilst this memoir is passing through the press, Dr Murie has published in the "Journal of Anatomy and Physiology," November 1870, an interesting paper on *Grampus rissoanus*, in which he points out that a laryngeal sac of moderate capacity exists in the toothed whales in the angle of junction between the enlarged epiglottis and the thyroid cartilage. He also describes a pair of folds within the larynx of Risso's grampus, which he regards as representatives of the vocal cords.

pendulous from the ventral wall. The organ consisted of a distinct corpus spongiosum urethræ, and of a strong corpus cavernosum. These bodies extended backwards for eight inches behind the crescentic folds above referred to. The corpus cavernosum then subdivided at a very obtuse angle to form the crura penis, which were firmly connected to the perichondrial investment of the larger and more rounded end of the rudimentary and still cartilaginous ossa innominata, which represented, therefore, the ischial elements of the pelvis.*

A strong muscle, which must be regarded as the erector penis, arose from the ischium, close to the attachment of the crus, and passed forward to be inserted into the corpus cavernosum. Large vessels and nerves were also seen passing to the different subdivisions of the penis. From the posterior border of each diverging crus, and from the sides of a tendinous raphé, which extended backwards from the end of the corpus spongiosum, a broad and strong muscle arose, which passed backwards along the side and under surface of the hinder end of the rectum, and ended close to the anus. This muscle was apparently the retractor penis. The corpus spongiosum had unfortunately been torn across, where the crura diverged, and the rest of the urethra, the bladder, testicles, &c., were not distinguishable, owing to the soft and injured state of the parts.

The arrangement of the parts at the entrance to the female passage has been described on p. 201. The vagina was traced forwards for six feet from the external orifice. Numerous irregularly arranged, and much subdivided, folds of the mucous membrane projected from its surface into the canal. The uterus was not recognised with any certainty, but a bag-like membranous organ, a part of which was seen to project through a long cut in the wall of the abdomen, on the day on which the baleen wreath of the fœtus was found loose in the abdominal cavity, was supposed to be a portion of that organ.

The kidneys possessed the lobular construction so characteristic of the form of those organs in the cetacea.

I shall reserve for another communication the description of the skeleton and joints, and such observations on the arrangement of the muscles as I was able to record. I may, however, state that the vertebral formula, both in the fœtus and in the mother, was—Cervical, 7 ; Dorsal, 15 ; Lumbo-caudal, 41 ; in all, 63. The outline of the cranial beak was in conformity with that of the head, which is so well represented in fig. 10 from the fœtus.

The following are a few measurements of the skull, taken with a tape-line, which may be of service in comparing it with the crania of other described whales :—

* I have described and figured the innominate bones and the sternum in the "Journal of Anatomy and Physiology," May 1870.

	Feet.	Inches.
From anterior border of foramen magnum over vertex to tip of beak,	20	3
From nasal process of superior maxilla to tip of beak,	16	6
From anterior border of foramen magnum to nasal process of superior maxilla,	3	9
Breadth across upper ends of nasal processes,	1	8
Breadth of a single nasal process.	0	6
Breadth of dorsum of beak—		
3 feet in front of nasal end of superior maxillaries,	7	0
4 „ „ „	6	10
5 „ „ „	6	8
6 „ „ „	6	6½
7 „ „ „	6	4½
8 „ „ „	6	1½
9 „ „ „	5	9
10 „ „ „	5	4
11 „ „ „	4	10
12 „ „ „	4	5
13 „ „ „	3	8
14 „ „ „	2	11½
15 „ „ „	2	1
Breadth at the tip of the beak,	0	7
Breadth between the orbits,	9	3
Length of lower jaw along the convexity,	21	2
„ „ in a straight line,	19	5
Depth of ramus at coronoid process,	2	6
Length of humerus,	2	2
„ radius,	3	9

Comparison with other Finners.—In instituting a comparison between the Longniddry whale and the other Fin whales which have been described by different authors, with the view of determining the species to which it should be referred, there is no need to compare it with either the *Balænoptera rostrata*, or the *Balænoptera laticeps*. For these animals never, apparently, exceed the length of 35 feet, and they differ so materially from the Longniddry whale in the number of vertebræ and ribs, that there can be no possibility of confounding it with either of them. My remarks, therefore, will be restricted to a consideration of those described specimens of fin whales which have reached the length of 40 feet and upwards. As I have not yet given an account of the skeleton of this large Finner, I shall almost entirely confine myself, on this occasion, to an examination of the external characters of these animals.

a. Sir R. SIBBALD, in his observations on rare whales cast on the Scottish coast,* describes two fin whales. One, he says, *rostrum acutum habet, et plicas in ventre;* the other *maxillam inferiorem rotundam, et superiore multo latiorem habuit.* The one with a sharp beak was cast ashore in 1690 near Burntisland, and measured 46 feet in length. It was in all probability an immature specimen of the Razor-back. The other with the rounded lower jaw, much wider than the upper, was stranded on the south side of the Forth, near the old castle of Abercorn, in 1692. It was a male, 78 feet long, and possessed

* Phalainologia nova. Edinburgh, 1692.

various points of resemblance to the Longniddry specimen. From the greater width of the lower jaw than of the upper, the latter was received within the circumference of the former. The upper jaw was contracted in front so as to terminate in a sharp end. The baleen was black, the longest plates having a vertical diameter of 3 feet, and they were fringed with black hairs. The bristles near the front of the palate were also black, and the intermediate substance was similar in character. The flipper was 10 feet in length, and $2\frac{1}{2}$ feet in its broadest part. The dorsal fin was 2 feet high, and in it was a rounded hole made by a leaden ball. Through this hole in its fin the whale had been recognised by the herring fishermen for nearly twenty years, and was called by them the Hollie Pyke. The back was black and the belly whitish. The blubber was $4\frac{1}{2}$ inches thick on the sides, and one foot on the head and neck.

Although it is customary for cetologists to regard this broad-jawed whale, described by SIBBALD, as the *Balænoptera musculus*,* yet the characters which I have just related are much more those of the species to which the Longniddry whale will have to be referred.

b. The best known of the large fin whales is the common Razor-back, the *Balænoptera musculus*, or *Physalus antiquorum* of GRAY, upwards of thirty specimens of which have come under the notice of, and been more or less perfectly described by, naturalists. Between the common Razor-back and the Longniddry whale there are many characteristic features of difference. In the former the beak is much more pointed than in the latter, and its width rapidly contracts from base to apex, instead of the borders forming a gentle convex curve; the flipper also is absolutely and relatively shorter in proportion to the length of the animal. In the *B. musculus*, captured near Gravesend, described by Dr MURIE,† whilst the animal was 60 feet, the length of the pectoral limb along the anterior curve was only 6 feet 3 inches; in the specimen 67 feet long, stranded at Pevensey, described by Professor FLOWER,‡ the flipper was 6 feet 9 inches; and in the specimen 61 feet long, beached last year at Langston harbour,§ the flipper had the length of 5 feet 4 inches. The external or labial baleen plates are in the common Finner neither so long nor so broad; their colour is slate-coloured, mottled, or striped with yellow, or white, or brown, or pale horn colour, the setæ are white, or yellowish-white; the palatal mucous membrane is pale, whilst in the Longniddry whale all these structures had a rich deep black colour. In the Razor-back, whilst the back is black, the belly is white or yellowish-white, instead of being mottled with silver-grey, or milk-white, tints. The blubber also is very much thinner in the common Razor-back,—not more

* ESCHRICHT, "Die Nordischen Wallthiere." VAN BENEDEN and GERVAIS, "Ostéographie des Cétacés," p. 188. Dr GRAY in his Catalogue says, probably it may belong to this species.

† Proc. Zool. Soc., Feb. 14, 1865.

‡ Idem., Nov. 28, 1865.

§ Idem., Dec. 9, 1869.

than four tons of oil were extracted from the Gravesend specimen,—so that the animal possesses very little commercial value, whilst several hundred pounds have been realised by the sale of the oil from the Longniddry animal. Further, it is very doubtful if the *Balænoptera musculus* exceeds the length of 70 feet; the Gravesend and Pevensey specimens, already mentioned, were both adult males, and yet they did not reach that length. Several specimens which have been referred to this species are, it is true, stated to have been longer than 70 feet; but of these, some, I believe, belong to another species, whilst it is doubtful how far the others have been measured with sufficient exactness. Moreover, the vertebræ in *B. musculus* are not so numerous, and do not apparently exceed sixty-one.

It is not necessary to compare the Longniddry whale with the *Physalus Duguidii*, described by Mr HEDDLE* and Dr GRAY,† as that animal is apparently nothing but a young specimen of the *B. musculus*.

c. In the year 1827 a fin whale, said to have been upwards of 80 feet long, was found floating on the North Sea, and towed into the harbour of Ostend, from which circumstance it has been customary to term it the Ostend whale. Unfortunately, no satisfactory account of the dimensions and external characters of this animal have been recorded, and the descriptions of the skeleton are in some respects imperfect. Zoologists, therefore, are by no means at one as to the genus or even species to which this whale ought to be referred. Dr GRAY places it in his genus *Sibbaldius*, and calls it *S. borealis;* ESCHRICHT has termed it the *Balænoptera gigas*, or *Pterobalæna gigas;* whilst VAN BENEDEN and GERVAIS, in their *Ostéographie*, have regarded it as merely an unusually large specimen of the *B. musculus*. Owing to the very imperfect data at my command, I cannot make any exact comparison between its external form and that of the Longniddry whale. I may state, however, that the length of the pectoral fin is said to have been about 10 feet; the distance from the point of the snout to the dorsal fin 61 feet; from the point of the snout to the genital organs 55 feet; that the back was black, and the belly whitish, the outer surface of the pectoral fin was black, and the baleen setæ also black.‡ In these respects it more closely approaches the Longniddry whale than it does the *B. musculus*. It must be admitted, however, that the measurements, which have been recorded by those who have described the animal, are not of a very reliable character, for, whilst VAN BREDA states its length to be about 84 feet, DUBAR makes it as much as 105 feet. I shall have again to refer to the Ostend

* Proc. Zool. Soc. 1856. † Catalogue, p. 158.

‡ The notices of this animal which I have read, and from which the above statements are drawn, are by M. VAN BREDA in Cuvier's "Hist. Nat. des Cétacés," p. 328; by ESCHRICHT in "Die Nordischen Wallthiere," p. 176; by LILLJEBORG in the Memoir translated for the Ray Society, p. 262; by Dr GRAY in his "Catalogue of Seals and Whales;" and by DUBAR in his "Ostéographie de la Baleine." For the opportunity of consulting DUBAR'S scarce pamphlet, I am indebted to my colleague Professor KELLAND.

whale when I describe the skeleton of the Longniddry whale, and to point out certain other points of correspondence between them. I may on this occasion, however, state that the small number of vertebræ, 54, described in the former animal is obviously owing, as DUBAR'S figure shows, to the loss, in the prepared skeleton, of several vertebræ in the caudal series. And there is good reason for believing that the double headed condition of the first rib which DUBAR figured in this creature, and on the presence of which Dr GRAY has to a large extent based his genus *Sibbaldius*, is merely an individual peculiarity, and may occur as a variety in more than one species of whale, just as it occasionally occurs as a variety in the human subject.

d. In the month of October 1831, a fin whale was observed floating dead on the surface of the sea off the mouth of the Firth of Forth, and was brought ashore near North Berwick, 23 miles from Edinburgh. It was purchased and anatomised by Dr and Mr FREDERICK KNOX. The skeleton was carefully prepared and publicly exhibited, and now forms the most noticeable object in the Natural History Department of the Museum of Science and Art, Edinburgh. Unfortunately no systematic description of this animal was ever published; but from one or other of the publications mentioned below* I have gathered the following particulars. The animal was a male, and measured 80 feet in length. The length of the head over the vertex was 21 feet; the pectoral limb 11 feet long; the circumference behind the pectoral limbs 34 feet, and even 52 feet when greatly distended with gas; the breadth of the tail 20 feet; the distance from the anus to the fork of the tail 21 feet.† The whole baleen, with its fringed edge, was of a clear shining black, and the longest plate measured 2 feet 2 inches in length, by 15 inches in breadth. Nothing is said as to the colour of the skin or the thickness of the blubber; but it is stated in the "Account," that "the fluid oil in the abdomen, particularly, was in very considerable quantity, and often gave a covering to the sea as far as the eye could reach."

KNOX named the animal the Great Northern Rorqual, or *Balæna maximus borealis.*

In July 1847, Dr J. E. GRAY stated to the Zoological Society of London,‡

* Abstract of a paper on the "Anatomy of the Rorqual (a Whalebone Whale of the largest magnitude)," by Dr ROBERT KNOX (Proc. Roy. Soc. Edin., March 18, 1833). "Account of the Gigantic Whale or Rorqual, the Skeleton of which is now exhibiting in the great rooms of the Royal Institution, Princes Street," by FREDERICK JOHN KNOX, surgeon, Edinburgh, 1835. "Catalogue of Anatomical preparations illustrative of the Whale, particularly the Great Northern Rorqual," by F. J. KNOX, Edinburgh, 1838. Although the name of Mr FREDERICK KNOX is attached to the catalogue, yet it would appear that the best part of it was from the pen of Dr KNOX ("Life of Knox," by Dr LONSDALE, p. 168). For the opportunity of consulting this scarce and valuable catalogue, to which I have referred on various occasions in the text, I beg to express my acknowledgments to my friend Dr JOHN ALEXANDER SMITH. The skeleton of this animal is figured in JARDINE'S "Naturalist's Library," vol. vi., Edinburgh, 1837.

† The Gravesend *B. musculus* was only 11 feet 1 inch between the points of the tail. The Pevensey Razor-back, about 13 feet; the Langston harbour specimen 11 feet. In the Pevensey whale the distance from the end of the tail to the middle of the anal aperture was 17 feet 9 inches.

‡ Proceedings, Part xv. p. 117.

that he had examined, though without being able to take any measurements, on account of its position, the skeleton of this animal. He considered it to be a *Physalus,* very nearly allied to the *Physalus antiquorum,* though it differed from a specimen of that animal taken at Plymouth in some of the characters of its cervical vertebræ. Since that time it has been customary to describe this great whale as the *Balænoptera musculus,* or *Physalus antiquorum.**

A comparison of the measurements, which I have quoted, with those of the Longniddry whale, given in the early part of this paper, and the very decided statement made as to the clear, shining, black baleen and setæ, will, I think, suffice to show that in its general proportions, and the colour of its baleen, the North Berwick whale resembled closely the Longniddry whale, and differed, therefore, in many most material points from the common Razor-back, so that it can no longer be regarded as of that species. The shape of its cranium, also, differs most materially from that of the *B. musculus.* Knox, in his catalogue, has given a few measurements of its skeleton, which, if compared with those of the Longniddry animal, will show that a close resemblance exists between these animals in this part also of their frames. The breadth between the orbits was 10 feet; the length of the base of the cranium measured in a straight line, 19 feet; the length of the lower jaw, 21 feet 4 inches; circumference of ramus about the middle, 4 feet; depth of ramus at coronoid process, 2 feet 7 inches; depth of body of hyoid, $8\frac{1}{2}$ inches; between the ends of the great cornua, 2 feet $6\frac{1}{2}$ inches; length of the humerus, 1 foot 11 inches; of the radius, 3 feet 10 inches. But it is right also to mention that there are differences in the skeleton, especially in the form of the sternum and the pelvic bones, and whilst the North Berwick whale has thirty ribs, it possesses as many as sixty-five vertebræ. The more complete comparison of the skeletons of these two animals I shall reserve for the second part of this memoir.

e. In 1847 Dr Gray described,† by the name of *Physalus Sibbaldii,* from the skeleton of an immature animal 47 feet long, in the museum of the Hull Literary and Philosophical Society, a new species of Finner, the baleen of which possessed a uniform deep black colour. In 1864 Professor Flower‡ discovered in the collection of the late Professor Lidth de Jeude, of Utrecht, the skeleton of a young finner about 44 feet long, which differed from the common Razor-back in possessing a much broader beak. He named it *Physalus latirostris.*§ Subsequently, on examining the skeleton in Hull, which Dr Gray had observed, he came to the conclusion that the animals were of the same species, and he withdrew his specific name in favour of the prior one given by

* Dr Gray, "Catalogue of Seals and Whales," p. 144; Van Beneden and Gervais, "Ostéographie," p. 172; and various other writers on the cetacea.

† Proc. Zoological Soc., June 8th.

‡ Idem, Nov. 8, 1864, and June 13, 1865.

§ This skeleton has since been acquired by the British Museum.

GAY.R Since then Dr GRAY has changed the generic name to *Cuvierius*, and terms the animal *C. Sibbaldii.** Those zoologists who do not break up the great genus *Balænoptera* into several smaller sub-genera, prefer to call the animal *Balænoptera Sibbaldii.* The Hull and Utrecht skeletons agree in possessing each 64 vertebræ; but whilst the former has 16 pairs of ribs, the latter has only 15 pairs. No information existed as to the external characters of either of the animals from which these skeletons were obtained, so that it was difficult to identify them with any of the species of whales known to zoologists, up to that time, only by their external appearances.

In 1867, however, Professor REINHARDT published an important memoir, in which he gave an account,† from notes furnished him by Mr HALLAS, surgeon to a whaling ship, of a Finner of which the Danish whalers had captured several specimens. This whale was known to the Icelanders as the Steypireythr. The back was blackish grey; down the sides the colour was lighter; the belly, behind the plicæ, was uniformly grey, the ridges blackish grey; the furrows between them, light grey; the caudal fin, blackish grey on both sides; the pectoral fins, blackish grey, spotted with lighter specks on the outer surface, but milk white on the inner. The baleen was uniformly black. The animal was about 80 feet long, and was said to have a dorsal fin not more than 7 inches high.‡ No measurements are given of the caudal or pectoral fins, or, indeed, of the proportions of the other parts of the body. Mr HALLAS also forwarded the skull, hyoid bone, and atlas of this animal, of which REINHARDT gives figures. Further, he states that the animal possessed 64 vertebræ and 15 pairs of ribs. In his remarks on this whale, REINHARDT compares it both with the *Balænoptera musculus* (*Physalus antiquorum*) and *B. Sibbaldii,* and considers that from its osteological characters it should be referred to the latter species.

By these observations, it was clearly established that a well-defined species of Finner exists in the northern seas, which differs from the common Razor-back, in possessing a greater number of vertebræ, a broader beak to the cranium, a greyish and not a whitish belly, and a uniform black baleen, instead of one mottled with various tints. In the distribution of the tints of the skin, in the uniform black colour of the baleen, and in the length of the animal, the Steypireythr obviously closely corresponds with the Longniddry whale. But what is even more important for the determination of the species, the cranium, atlas, and hyoid, as far as one can judge from REINHARDT'S figures, are almost identical in

* Appendix to Catalogue of Seals and Whales, p. 380.

† Vidensk. Meddelelser fra den Naturhist, Forening i Kjöbenhavn, 1867. Translated in "Annals of Nat. Hist.," November 1868.

‡ Although the end of the dorsal fin had been removed from the adolescent Longniddry whale before my measurements were taken, yet sufficient had been left to show that this fin had been more than 12 inches high. Consequently, I do not think that the shortness of the dorsal fin is so definite a character as REINHARDT supposes.

form with the corresponding bones in the Longniddry whale. Hence we arrive at the conclusion, that the Longniddry whale is a specimen of the *Balænoptera Sibbaldii*, or *Physalus Sibbaldii* of GRAY.

Two years before the publication of REINHARDT'S memoir, a fin whale, about 54 feet long, came ashore alive at Gothenburg, on the west coast of Sweden. It was secured by Professor MALM, the superintendent of the Museum in that city, and was carefully examined by him. He published an elaborate monograph, with numerous photographic illustrations, descriptive of the capture of the animal, its form, colour, proportions, and dimensions, with a detailed account of the skeleton, and a number of observations on its visceral anatomy.* The animal was a male, and had not reached its full growth. Its colour was a deep slate tint, with somewhat paler tints on the sides, whilst the lower surface was mottled with patches of milk white, of different sizes and shapes. The flippers were white on the inner surface, and the lobes of the tail at the under part whitish. The distance from the anterior part of the base of the flipper to its free extremity, measured in a straight line, was 7 feet 4 inches, whilst the distance between the extreme points of the tail was about 11 feet. The baleen was uniformly of a deep black slate colour, whilst the hairs at the free margins of the plates were of a brown soot colour. The vertebræ were 63 in number, and there were 15 pairs of ribs. MALM considered it to be a new species, and named it *Balænoptera Carolinæ*.

From a comparison of its osteological characters with those of the *B. Sibbaldii*, more especially the resemblance in the breadth of the beak, the form of the nasal bones, the relative and absolute length of the metacarpals and phalanges, and the spine of the axis, as well as from the uniform dark colour of the baleen, Professor FLOWER came to the conclusion,† that MALM'S whale ought not to be regarded as a distinct species, but was merely another immature specimen of the *Balænoptera* (*Physalus*) *Sibbaldii*. In this conclusion he has been supported by Professor REINHARDT, who states‡ that, in his opinion, "ESCHRICHT'S 'Tunnolik,' the 'Steypireythr' of the Icelanders, and, finally, the whale described by MALM, are only one and the same species, which appears to be one of the most common in our northern seas, and the systematic name of which must be *Balænoptera Sibbaldii*."

If I am correct in regarding the Longniddry whale as the *B. Sibbaldii*, then—Professors FLOWER and REINHARDT being also correct in their supposition—its characters should closely correspond, allowance being made for the different sizes of the two animals, with those of MALM'S whale. In the colour, both of the skin and the baleen; in the shape of the tail and pectoral fin; in the relative pro-

* "Monographie illustrée du Baleinoptère," Stockholm, 1867. For the opportunity of consulting this work, three copies only of which are, I believe, in this country, I am indebted to my friend, Mr J. W. CLARK, of Cambridge.

† Proc. Zool. Soc., March 12, 1868. ‡ Memoir, cited above.

portions of these parts to the length of the entire body; in the form of the beak; and in the curve of the lower jaw, the resemblances are very striking. The osteological characters have also much in common; but the consideration of these I shall not enter into on this occasion.

The comparison I have now made between these different specimens of Finners, leads me to the conclusion that the following should be referred to the *Balænoptera Sibbaldii*:—

The North Berwick whale.

The Hull skeleton.

The Utrecht skeleton, now in the British Museum.

The Gothenburg whale.

The Steypireythr.

The Longniddry whale.

And, in all probability, the Ostend whale, and Sibbald's "Balæna tripinnis quæ maxillam inferiorem rotundam, et superiore multo latiorem habuit."

EXPLANATION OF THE PLATES.

With the exception of fig. 1 Plate V., of figs. 19, 20, 21, 22, 23, 24, 25, 27, 28, Plate VII., and of fig. 29 Plate VIII., the illustrations have been very carefully drawn, under my superintendence, by Mr J. B. Abercrombie, from nature. Fig. 27 was drawn by Mr Coughtrey, fig. 28 by Mr Foulis, and figs. 19 to 25 inclusive, and fig. 29, were sketched by myself from microscopic preparations. As far as possible, the specimens from which the drawings were taken have been preserved in the Anatomical Museum of the University of Edinburgh. When not otherwise stated, the drawings represent portions of the adolescent animal.

Plate V.

Figure 1. Side view of the Longniddry Whale. This drawing was constructed from photographs, from pencil sketches, and from a water-colour sketch by Mr Sam. Bough. The lower jaw is represented somewhat out of position so as to give a side view of the baleen and of the dorsum of the tongue.

Figure 2. The falcate dorsal fin of the fœtus.

Figure 3. The horizontal tail of the fœtus.

Figure 4. The abdominal plicæ of the fœtus, showing bifurcations of the ridges.

Figure 5. Supero-anterior surface of the left flipper of the fœtus. The outlines of the bones of the antibrachium and of the four digits are represented. The posterior edge of the flipper was much thinner than the anterior.

Plate VI.

Figure 6. The clitoris, below which is the opening of the urethra, and the folds of mucous membrane, on the floor of the vestibule. The labia majora have been drawn asunder to expose these parts.

Figure 7. The orifice of the nipple fossa, displaying the nipple with the pedunculated papillæ at its summit.

Figure 8. The anal orifice, with the rugæ of the integument converging to it.

Figure 9. The ventral wall of the fœtus, displaying the penis with the crescentic folds of skin at its root, the median perineal raphé, with a rudimentary nipple fossa on each side, and, more posteriorly, the anal orifice.

Figure 10. Dorsum of the beak of the fœtus. The curved outline of the beak; the dorsal median ridge; the form and direction of the blow-holes, which are partially open, and the intermediate groove are all represented.

Figure 11. A portion of the mammary gland to show the rugose character of the mucous lining of the duct, one-half the size of nature.

Figure 12. One of the large, irregularly quadrilateral, labial, baleen plates, much reduced in size.

Figure 13. A vertical section through the intermediate substance of the baleen, displaying its laminated appearance. The subsidiary blades are shown, two of which have been cut short. On the upper or palatal surface, the clefts between the laminæ of the plates, into which the palatal folds of mucous membrane fit, may be seen.

Figure 14. The baleen plates and intermediate substance of the fœtus, the size of nature. One of the plates, with the thin layer of intermediate substance on each side, has been partially separated from the others.

Figure 15. Portion of the palatal mucous membrane of the fœtus. At the upper end of the figure is the lip; lower down the elongated folds for the larger labial baleen plates, and at the lower end the subconical papillæ from which the bristle-like subsidiary plates arise. The tubular papillæ are not represented in the drawing, as they had all been broken off before the drawing was made.

Figure 16. Palatal surface of a part of the fœtal baleen wreath, with a side view of one of the plates. The elongated clefts between the laminæ of the labial plates and the polygonal pits for the sub-conical papillæ are shown; as the tubular papillæ are still within the blades, their broken ends may be seen in part occupying the clefts and pits.

Plate VII.

Figure 17. Portion of the fœtal membranes; *a*, the non-villous surface of the chorion; *b*, villous surface. Between *a* and *b* the elongated marginal folds of the chorion may be seen. *c*, Divided end of one of the arteries of the chorion.

Figure 18. A large triangular fold of the chorion, displaying the reticulated arrangement of the villi on its surface.

Figure 19. Vertical section through a portion of a baleen plate to show the tubes, with the lamellæ and black pigment granules. × 40 diam.

Figure 20. Transverse section through a portion of a baleen plate. The entire antero-posterior diameter is represented. The tubes are divided transversely. Some are empty, others contain the tubular papillæ, and in some of these the transversely divided ends of the contained blood-vessels may be seen. Both the tubular and cortical lamellæ, with numerous black pigment granules, are represented in the drawing. × 40 diam.

Figure 21. Epithelial cells from the outer layers of two adjacent tubular systems. At the lower part of the drawing some interstitial cells are represented. × 200 diam.

Figure 22. Transverse section through one of the setæ of a baleen plate. The shaded central portion represents the soft papilla, in which a transversely divided blood-vessel is represented. × 40 diam.

Figure 23. Vertical section through a portion of the intermediate substance; the clefts extending into its substance, in which the intermediate papillæ are lodged, are seen at the upper part of the section. × 40 diam.

Figure 24. Epithelial cells from the intermediate substance. × 200 diam.

Figure 25. Red blood corpuscles from the blood in the vessels of the baleen plate of the *B. rostrata*. × 1200 diam.

Figure 26. Portion of one of the elongated folds (pulp-blades) of the palatal mucous membrane. The tubular papillæ are dependent from the lower edge of the fold. Size of nature.

Figure 27. Vertical transverse section through the pulp-blades, intermediate substance, and imbedded parts of the baleen plates of *B. rostrata*, the blood-vessels of which have been injected; *i*, the vessels of the intermediate papillæ; *c*, the vessels of the cortical papilla; *t*, the elongated vessels of the tubular papillæ.

Figure 28. Arch of the aorta and great vessels of the fœtus. *x*, the ductus arteriosus; *a*, right coronary artery; *b*, brachio-cephalic; *c*, left carotid; *d*, left subclavian; *e*, right carotid; *f*, right subclavian; *g*, right posterior thoracic; *h*, right axillary; *i*, right internal mammary; *k*, right cervico-facial; and *l*, right internal carotid; *m*, left cervico-facial; and *n*, left internal carotid; *o*, left posterior thoracic; *p* and *q*, left axillary and internal mammary arteries.

PLATE VIII.

Figure 29. Vertical section through the integument. It shows the elongated papillæ, the comparatively thin cuticle containing a quantity of black pigment, and the subcutaneous tissue, with the small arteries entering the bases of the papillæ. × 20 diam.

Figure 30. Dorsal surface of the pharynx and commencement of the œsophagus of the fœtus; *p h*, the pharynx displaying the fibres of the constrictors and the longitudinal raphé. The upper part of the pharynx has been cut across, and the soft palate *v* is displayed; passing under it is an arrow lying in the bucco-pharyngeal canal. Immediately behind the velum a portion of the epiglottis is visible.

Figure 31. The interior of the cavity of the pharynx of the fœtus opened into by a posterior median incision; *v*, the velum; *e*, the epiglottis, the letter is placed on the cushion, which corresponds in position to the bar-like rod of fibro-cartilage; *l*, the lappet-like fold of mucous membrane which invests the superior horn of the arytenoid cartilage, the outline of which may be seen in the figure. The upper arrow is in the bucco-pharyngeal canal, the lower is in the windpipe.

Figure 32. Portion of the intestinal tube. *v*, the superior mesenteric vein which receives numerous rootlets from the gut; *m*, the moniliform tube, giving off numerous small arteries to the wall of the intestine; *n*, the sympathetic nerve, also sending branches to the gut; *p*, the peritoneal coat turned down. At the right cut edge of the intestine the valvulæ conniventes of the mucous coat are shown.

Figure 33. A portion of the beaded mesenteric vessel, displaying the series of dilatations and constrictions. At the right side the tube has been opened, and the corrugated folds of the inner wall may be seen.

Figure 34. One of the dilated portions of the beaded vessel. The lacunary system on its surface is represented. The darkly shaded, elongated, and globular bodies, *l l*, are the small lymphatic glands.

Figure 35. Annular and spirally arranged plate of cartilage from a bronchial tube.

Figure 36. Front view of the larynx and hyoid apparatus; *h*, the body of the hyoid with the stylo-hyal and great cornu on each side. Immediately above the hyoid body is the orifice of the bucco-pharyngeal canal, the arrow lying in which has emerged below through the œsophagus; *th*, the thyro-hyoid muscle; *sh*, the stylo-hyoid muscle; *t*, the thyroid cartilage; *c*, the cricoid; *cm*, the constrictor muscle of *p*, the laryngeal pouch. The bifurcation of the trachea and the supplementary right bronchus are seen, and the arrow passed through the left bronchus emerges superiorly, immediately behind the posterior horn of the left arytenoid cartilage.

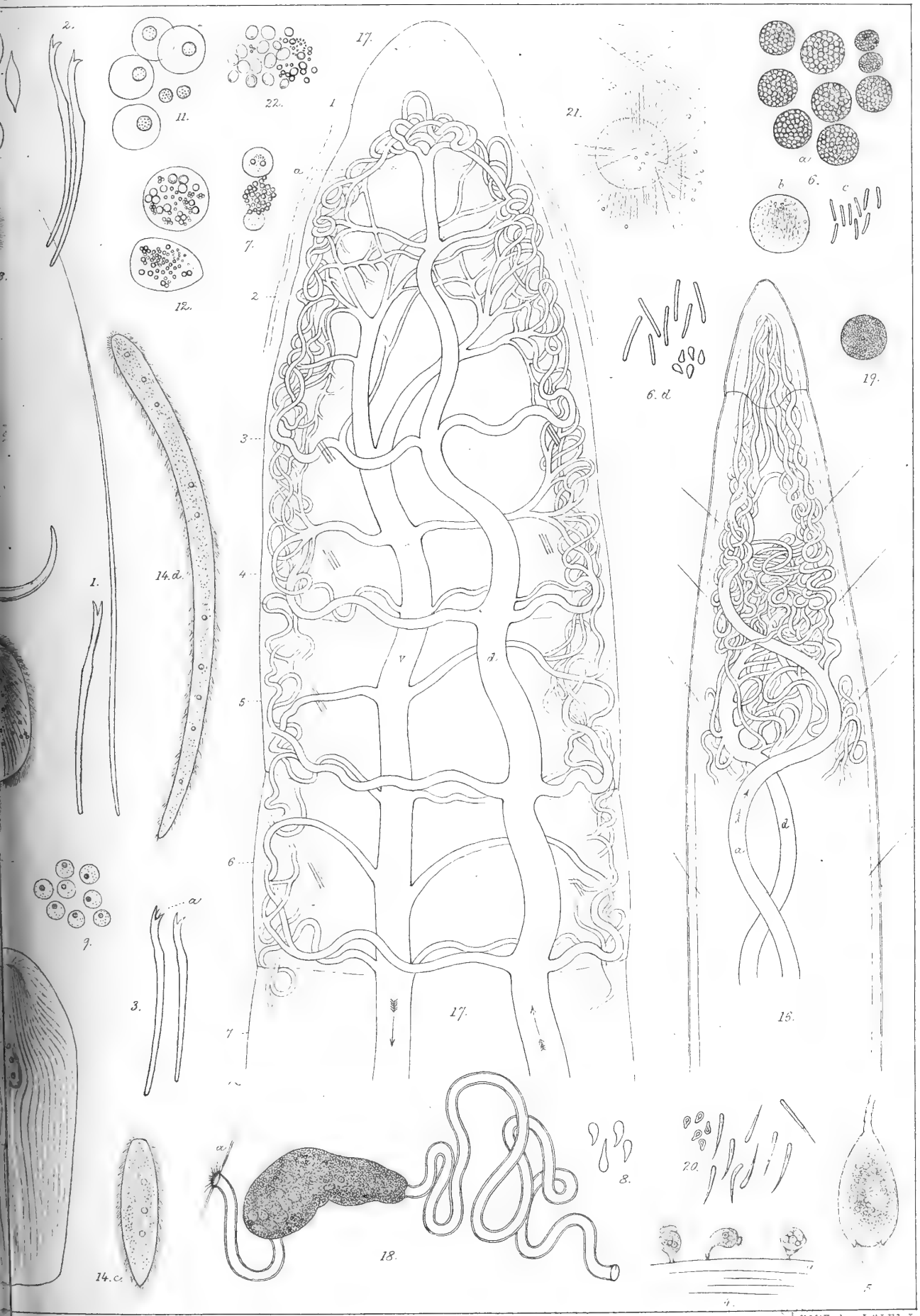
Figure 37. Front view of the larynx and trachea; the laryngeal pouch has been removed and the cartilages dissected, *t*, the thyroid cartilage; *c*, the cricoid with its plate-like processes; *a*, the body; *s*, the anterior, and *i*, the posterior cornu of the arytenoid cartilage; *ct*, the inferior cricothyroid membrane. The barb of the arrow passed through the left bronchus, lies immediately behind the posterior horn of the left arytenoid cartilage, and in front of the body of the cricoid, which is in deep shadow.

Figure 38. View of the interior of the larynx from behind, obtained by cutting through and turning outwards the body of the cricoid, and the membrane connecting the anterior horns of the two arytenoid cartilages; *e*, the epiglottis; *c*, the cricoid; *l*, the lappet of mucous membrane enclosing *s*, the anterior horn of the arytenoid; *i*, the posterior horn. To the inner side of the anterior horn is the fold of mucous membrane, which may represent a false vocal cord.

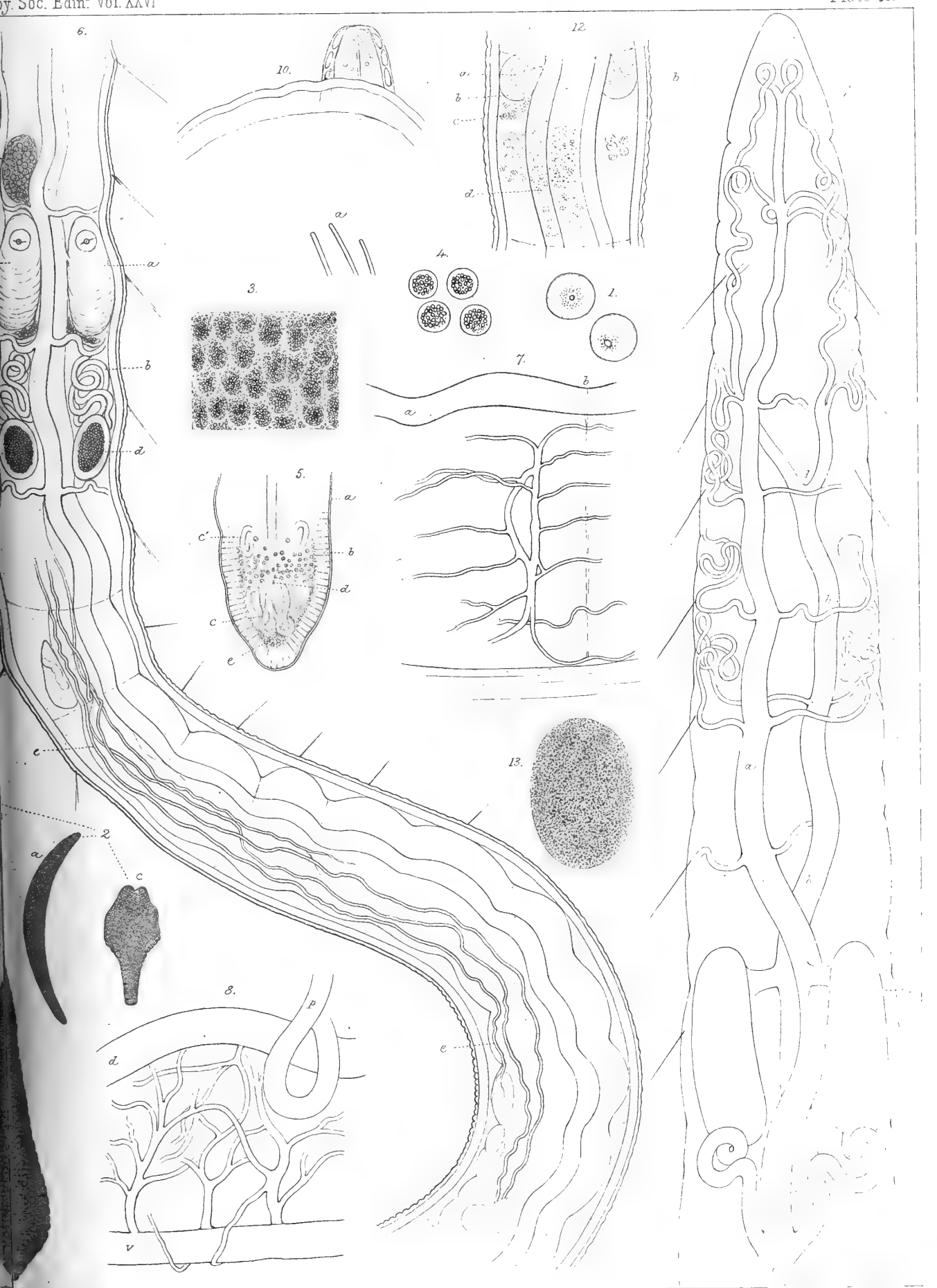
Figure 39. The posterior nares viewed from below.

Figure 40. The anterior nares or blow-holes viewed from above; the walls are separated to show the internal foldings.

Figures 35 to 40 inclusive are from the fœtus.



W. H. Mc Farlane Lith^r Edin^r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XII.—*On some Points in the Structure of* Tubifex. By W. C. M'Intosh, M.D., F.R.S.E. (Plates IX., X.)

(Read 2nd May 1870.)

At least two species of *Tubifex* are abundant in Scotland, one of which is, perhaps, more prevalent in streams, the other in lakes. The former is common at the margin of the river Tay, when the water is low, in sandy tubes of little tenacity, and often in tunnels formed amongst the wet sand under stones, just as many of the marine annelids occur. Its length varies from three-fourths of an inch to an inch and a-half when stretched, and the segments range from fifty to seventy, the average number probably being sixty. The body is of various shades of dull fawn or pale madder-brown, somewhat interrupted by the pale bands at the junctions of the segments, and streaked by the reddish dorsal vessel; or, in summer, marked anteriorly by the whitish mass of the reproductive organs. It is easily recognised amongst its fellows by its faintly purplish or lilac hue, as well as by its peculiar mode of progression; and not a few are observed with reproducing heads and tails. This form, perhaps, has most claim to be called *Tubifex rivulorum.*

The body is tapered towards head and tail, distinctly segmented, and much shorter and stouter than the succeeding species. Moreover, the length of the bristles does not equal the diameter of the body. The snout is somewhat conical, with the puckered mouth at its posterior margin, near the first crenation, which indicates its separation from the succeeding segment. There are many motionless microscopic processes on the surface of the snout in well-developed specimens, and the same organs occur on the bristle-papillæ and the caudal segment. Such have generally been regarded as tactile papillæ. Though analogous, they are not quite homologous with similar processes in the Turbellaria. The second segment bears a long bristle at each side dorsally, and three hooks, one of which is small. The third segment has two bristles and three hooks on each side superiorly; ventrally four hooks on each side. Generally the inferior hooks are five or six in number on each side, one being short and in process of development. The bristles (Plate IX. fig. 1) seem slightly stouter than those of the longer form, and no serrations are visible on the sides. M. d'Udekem noticed in his form a bristle with a brush-like tip, and has figured the same,* but though Mr Lankester has seen such in examples of *Tubifex*

* Hist. Nat. du Tubifex, &c.; Mém. couronnés et Mém. des sav. étrangers, &c.; l'Acad. Roy. de Belgique, tom. xxvi. p. 11, Plate II. fig. 8.

from the Thames, they have never occurred in those found in this neighbourhood. The number of pairs of bristles in front ranges from twenty-one to twenty-three. The hooks are gently curved organs, with a bifid tip, and a distinct swelling or shoulder about the upper third, from which point they taper towards the base. Those accompanying the bristles anteriorly (Plate IX. fig. 1) slightly differ in their curvature from those of the ventral series (Plate IX. fig. 2). In the other and longer form (with about 150 segments) from the lakes, the fourth segment has a pair of bristles, and the latter increase in length till the twelfth segment is reached, after which they gradually diminish and disappear about the fortieth. There is a small papilla where each bristle-bundle passes through the skin, and the tips of the hairs are delicately serrated or roughened, the serrations being directed distally. In this form the bristles are larger than the diameter of the body, and hence it differs from *Nais scotica* and the *Nais lacustris* of DALYELL. The hooks commence with the bristles, and besides those accompanying the latter, form two rows, as usual, inferiorly, which rows in front consist of groups of four hooks. Those accompanying the bristles (Plate IX. fig. 3) are more closely forked at the tip, and if examined under a power of 700 diameters show certain processes in the fork (*a*), a fact first pointed out to me by Mr LANKESTER, whose larger specimens from the Thames exhibited this and other peculiarities in a marked manner. These are also less shouldered, less curved, and somewhat more elongated than the inferior hooks. The latter in each form of *Tubifex* continue after the last bristle-bundle, and thus form four rows posteriorly, the terminal segment only being bare. M. D'UDEKEM's representations of the hooks,* though easily recognisable, deviate a little from the foregoing, and the same may be said of M. CLAPARÈDE's figures of the hooks of his *Tubifex papillosus*.†

Body-Wall.—M. D'UDEKEM speaks of the epidermis as being separable from the chorion by the aid of an alkaline solution, but I have not been able to disengage it as a distinct layer either by the action of chemicals in the fresh animal, or in transverse sections of the body-wall. M. CLAPARÈDE does not mention the superficial layer as a distinct coat, but groups it with the subjacent, under the name of cuticle.‡ The cuticular surface (or layer) is quite homogeneous, but the chorion which is incorporated with its inferior surface is distinctly cellulo-granular, as described by GRUITHUISEN in Nais (*Chætogaster*), and by BUCHHOLZ in Enchytræus. This is most distinctly marked at the snout and tail, where the layer is thickened. The other layers in *Tubifex* are a belt of circular muscular fibres, and a longitudinal muscular coat. M. CLAPARÈDE gives an ideal section of *Limnodrilus*, a form which differs from *Tubifex* in the

* *Op. cit.* Pl. II. figs. 6 and 7.
† Beobach. über Anat. u. entwicklung. &c., p. 25, Pl. XIII. fig. 15.
‡ Recherches Anat. sur les Oligochètes, p. 7.

absence of the bristles and other points, in which he shows the longitudinal muscular coat separated into six divisions, viz.,—two dorsal, two lateral, and two ventral. I have not been able to see this arrangement in the transverse sections of the minute forms of *Tubifex*, and even the separation at the bristle-sacs is comparatively indistinct. This ambiguity is no doubt due to the small size of the specimens. In the living animals, however, certain rows of papillæ may occasionally be observed, which probably mark the dorsal and ventral lines. The circular muscular coat is much thinner than the longitudinal. The latter forms in transverse section numerous well-defined fascicles, and in the fresh condition these are bounded internally by a membranous layer with many cells. At the period of reproductive activity the neighbourhood of the eleventh segment becomes almost opaque from a cellular covering. This appears to be due to an increased development of the cellulo-granular elements of the chorion.

Adhering by short stalks to the walls of the body posteriorly in both forms, were numerous parasitic vorticellæ (Plate IX. figs. 4 and 5), having an active crown of cilia, and numerous globules and granules in their interior. In some examples these were very numerous, often in groups of three or four, but they rarely occurred on the terminal segment, except in decomposing individuals. In contraction the base becomes finely corrugated. The free motion of the tail of the worm in the water places these organisms under very favourable conditions for aeration and food. Fungi, also, may frequently be seen growing on the disorganised anterior segments, while the posterior are in full activity. Fresh water annelids, indeed, are prone to have such growths, just as young salmon are under similar circumstances. The anterior part of the body becomes first attacked, dissolving into a granular mass swarming with fungi and infusoria. The segment immediately behind the decayed portion shows its integument corrugated and thrown into transverse rugæ, while the perivisceral corpuscles and the blood have disappeared. The next septum is strongly contracted, and in marked contrast to the succeeding segment, within which are many perivisceral corpuscles of the ordinary appearance, and whose dorsal vessel pulsates vigorously.

Perivisceral Fluid and Corpuscles.—The perivisceral fluid occupies, as usual, the space within the body-wall all round, from the tip of the snout to the tail, surrounding and bathing the digestive and other structures contained therein. In *Tubifex rivulorum*, the perivisceral corpuscles (Plate IX. fig. 6, *a*), are very conspicuous, and differ characteristically from those of the succeeding form from the lakes.* They are rounded bodies filled with circular granules of consider-

* Whatever result more extended investigations may give with regard to the specific value of characters derived from the shape of these bodies, it is right that the name of Dr Thomas Williams should be honourably remembered in conjunction therewith. *Vide* his paper on the "Blood-proper and Chylaqueous Fluid of Invertebrate Animals," Philos. Trans. P. II., 1852.

able size, and in the living animal undergo various changes in shape by pressure against each other, the body-wall and viscera of the worm. On extrusion into the surrounding water they become very transparent, and their broken contained granules collect together at one point (Plate X. fig. 1). Tincture of iodine and chromic acid colour them deep yellow, while sulphuric ether does not materially affect them. Dilute glycerine first corrugates, and then causes them to burst, giving exit to the contained clear granules (Plate IX. fig. 7), which measure about $\frac{1}{800}$th of an inch in diameter. Some of the corpuscles are smaller, and their contained granules less in proportion. Besides the foregoing, there are many elliptical, curved, and granular corpuscles (Plate IX. fig. 8) in the perivisceral space. In the elongated form the perivisceral corpuscles are less conspicuous both as regards number and size. The larger bodies in this case are rounded cells (Plate IX. fig. 9), filled with much more minute granules than in the preceding form, and many show a granular nucleus. The other corpuscules (Plate IX. fig. 10) are elliptical or fusiform, flattened, transparent and non-granular, and often longer than the diameter of the ordinary granular corpuscle just described. As contrasted with a gland-cell from the intestinal wall, the perivisceral corpuscle in the former case is widely different, while in this it has much smaller granules, is pale, and easily distinguished from the other with its highly refracting yellowish granules. In a form occurring abundantly in certain lakes with the latter, and referable to M. Claparède's genus *Limnodrilus*, the perivisceral corpuscles are remarkably developed. They are larger than usual, very transparent, and frequently show a somewhat puckered outline within the body of the worm. They also have the peculiarity of adhering here and there in considerable numbers to the intestinal coating. Few or none of the ordinary fusiform or other bodies are present. On extruding these corpuscles into the water they swell out, and show a large granular nucleus, the rest of the cell being quite translucent. Moreover, both cells and nuclei have a nearly uniform diameter throughout the fluid. On contrasting these corpuscles (Plate IX. fig. 11) with the gland-cells from the intestine (Plate IX. fig. 12), a very marked difference is observable. The former are quite transparent—with the exception of the nucleus, becoming slightly granular only after remaining many hours in the water. They have nuclei of definite size and structure, which retain their shape and appearance after the bursting of the cell-wall. Acetic acid and ether only show the structure just described more clearly. On the other hand, I have watched the gland-cells from the intestine under water and various reagents side by side with the others, and for a considerable time; but I do not feel able to say that nuclei or other contents than the refracting granules have been detected. The gland-cell may be set in motion, rolling over and over, so as to expose it all round, yet not a trace of a nucleus is seen. In all the forms there is thus a considerable

histological difference between the two sets of cells; and both differ very much from the cells on the inner surface of the intestinal wall (Plate IX. fig. 13.)

I have been somewhat minute in observing this point, because it has generally been stated that the perivisceral corpuscles have their origin from, or are closely connected with, the gland-cells which cover the intestine and dorsal vessel. M. D'UDEKEM is stated by Mr LANKESTER, in his recent paper on Chætogaster,* to have connected the two in his memoir on *Tubifex*, but such is not my impression. It is true the author describes two kinds of "glandules" covering the intestine and the dorsal vessel, viz., nucleated brownish "glandules," and colourless "glandules" having oily contents, and says they represent the liver of the higher animals,—secreting a liquid for assisting digestion. In speaking of the perivisceral fluid, moreover, he omits all notice of the origin or relationship of the corpuscles; and adds that the number and large size of these "globules lymphatiques" constitute one of the differences between the young *Tubifex*, on its extrusion from the egg, and the adult. He hints at no connection between the two structures. Mr LANKESTER, also, in the same paper does not fully express the published opinions of M. CLAPARÈDE on this point. He says, "There is a very distinct relation between the abundance of the perivisceral granules and cells, and the abundance of the brownish granules which surround in masses the dorsal vessel and its ramifications on the stomach or intestine. CLAPARÈDE, in his 'Recherches sur les Oligochètes,' has spoken of the brown-yellow 'hepatic' tissue of the intestine in *Lumbricus* being continued to and surrounding the dorsal vessel, and has hinted (but only obscurely) at some connection between the perivisceral cells and the supposed hepatic tissue."† Now, in the first place, in the memoir alluded to, M. CLAPARÈDE did not specially refer to *Lumbricus* so much as to those genera included under his family of "Oligochètes Limicoles" (*Tubifex, Limnodrilus, Clitellio, Lumbriculus, Stylodrilus, Enchytræus*, &c.), whose structure formed the text of his work. *Chætogaster*, of course, would come under the same head. M. CLAPARÈDE states that the pigment-cells of the intestine have generally been considered as hepatic, and points out that the said cells have as much connection with the dorsal vessel as with the intestine; that in *Lumbriculus variegatus*, for example, the cellular coating, which ceases to cover the intestine at the sixth segment, continues on the dorsal vessel to the fourth, and, moreover, the coating follows certain branches of the dorsal vessel. Further, he adds, that the intimate connection between the supposed hepatic structure and the vascular system is extremely evident in the true Lumbrici, and concludes with the following:—"Il est donc très-im-

* Trans. Linn. Soc. vol. xxvi. p. 637.

† Mr LANKESTER has altered his views here.—*Vide* his paper in the Quart. Jour. of Micros. Sc. vol. v. N. S. p. 109.

probable que ces cellules versent de la bile dans la cavité de l'intestin. Il est beaucoup plus vraisemblable qu'elles déversent leur contenu dans la cavité périviscérale." He reiterates this opinion in his recent beautiful and accurate memoir on the Histology of the Earthworm.* Dr GRUITHUISEN, indeed, clearly anticipated most of the subsequent observers in regard to the connection between this glandular coating and the perivisceral fluid, which he termed the chyle. In describing the glands which envelope the intestine of his *Nais* (Chætogaster) *diaphana*, he observes, "Diese Drüs'chen bilden das, was bei höhern Thieren die Chylusdrüsen sind, und ergiessen den Chylus unmittelbar in den Raum zwischen der musculösen Haut und dem Darmcanale."† This author, moreover, notes the peculiarity that in a single "Mutternaide" of *Chætogaster diastropha*, he found in December that the chyle-corpuscles were larger than usual, and seems to think that there is a connection between chylification (referring to the perivisceral fluid) and generation. Dr THOMAS WILLIAMS,‡ again, was strongly of opinion that the long coils of the blood-vessels anteriorly in his *Nais filiformis* (probably *Tubifex*) and the perivisceral branches elsewhere in the body of this worm, were specially intended for absorbing from the perivisceral (his "chyl-aqueous") fluid elements by which the blood-proper is formed and replenished. It will therefore be seen that the supposition thrown out by my friend Mr LANKESTER that "the yellow glandular tissue" surrounding the alimentary canal "may have but little to do with the secretion of digestive juices, or, at any rate, may have an additional and most important connection with the production of the corpuscles of the perivisceral fluid, and may serve to place that fluid in organic relation with the liquid of the closed vascular system of the intestine, and the contents of the digestive tract," is by no means new. It appears, indeed, to be the result arrived at by Dr FRITZ RATZEL from an examination of the literature of the Oligochètes previous to the appearance of the foregoing; the author, moreover, assigning the perivisceral fluid the function of a communicating medium between the digestive and circulatory systems. Further, I have not seen anything to support the idea of Mr LANKESTER that the abundance or scarcity of the "granules" in the perivisceral fluid depends on the condition of the glandular coating of the intestine and dorsal vessel. The glandular investment presents the same appearance whether the corpuscles be few or many, and the agglomerations of granules shown by him most readily take place in such a highly coagulable fluid. For my part, I have no objection to offer to any of the theories advanced on this subject, so far as they rest on actual observation and not on mere conjecture. In *Tubifex* and its allies the perivisceral fluid is an eminently coagulable and vital

* Zeitsch. f. wiss. Zool. Bd. xix. (1869), p. 614.

† Ueber die *Nais diaphana*, &c., Nova Acta Acad. Leop. Carol. Tom. xiv. Pt. i. p. 411.

‡ Report Brit. Assoc. 1851, p. 182; and Philos. Trans. Part ii. 1852, p. 625.

fluid, and, as has long been supposed, doubtless performs important functions in the animal economy; as, indeed, the observations of FREY and LEUCKART, DE QUATREFAGES, and Dr WILLIAMS, show it does in other invertebrate animals. I think, however, that too little attention has been bestowed upon the inherent properties of the fluid itself. Perhaps the remarkable corpuscles contained therein are the products of such inherent properties, and not necessarily derived from its surroundings. If the glands covering the intestine discharge their contents into the perivisceral fluid, as most authors believe, such a discharge probably only furnishes materials for the evolution of the special properties of the liquid. It is well to bear in mind, also, that in the clearly defined group of the Nemerteans, a fluid identical in appearance, coagulable nature, and in the presence of definite corpuscles, occurs within a special muscular sheath on the dorsum of the intestine. This chamber has smooth walls, and contains, besides, the proboscis, which, as it were, is invaginated within it. The glandular elements, which exist in vast numbers in the walls of the digestive tract, cannot thus communicate directly with the fluid.

In the perivisceral space of one example was a curious parasitic larva (Plate X. fig. 2) which moved backwards and forwards in its chamber. It lengthened its body into the shape shown at *a*, then contracted itself as in *b*, forming a club with a large rounded head, and finally assumed the appearance figured at *c;* after which it again elongated itself and repeated the same contractions. Its structure was minutely granular, with a streak at the anterior end. It appears to be the same form as that described subsequently from the lobule of the testis (p. 265).

Digestive System.—Granular Glands.—Anteriorly there are some finely granular glands at the sides of the œsophagus; and by-and-by numerous larger glands cover the entire external surface of the alimentary canal, and envelope the dorsal blood-vessel. These are somewhat pedicled structures, consisting of a fine external membrane containing numerous distinct granules of an orange or pale brownish hue (Plate X. figs. 3 and 4). When these bodies are extruded into the water, the contained granules show very evident molecular movements, and in a short time escape by the bursting of the cell-wall, their movements continuing in the surrounding fluid. The yellowish granules also occasionally group themselves together, and larger granules are formed here and there, apparently by the union of several. All the granules refract the light very strongly. The gland-cells are rendered more translucent by acetic acid, which, however, does not affect the granules. On the addition of sulphuric ether the residue clearly shows that their composition is of a fatty nature. Dr BUCHHOLZ* is of opinion that the pigment-granules of these cells in *Lumbriculus variegatus* is a

* Beiträge zur Anat. der Gattung *Enchytræus*, &c. Schriften der Physik. ökonom. Gesellschaft in Königsberg, 1862, p. 108.

modification of chlorophyll. This author, moreover, shows a distinct nucleus in all his figures of the gland-cells of the same worm, and M. Claparède describes a nucleus in those of *Lumbricus*. So long as the cell is filled with the granules, it would be a very difficult thing to make out a nucleus, and the large number of nucleated cells from other parts which get mixed up with these in the field of the microscope necessitates some caution in observing. As previously stated, I have not succeeded in seeing a nucleus while the granules were within their investment, nor on watching their extrusion has such been observed. The same result was arrived at after a careful scrutiny of highly favourable longitudinal and transverse sections of the alimentary canal of *Tubifex*, and after manipulation of the fresh specimens with carmine.

Amongst the sandy mud and Diatomaceæ in the intestinal canal, are numerous examples of an *Opalina* (Plate IX. fig. 14, *a*, *b*, *c*, *d*). Some are about $\frac{1}{40}$th of an inch long, and had the various shapes shown in the figures. The species is probably identical with that found in other minute fresh-water annelids. A few had a swollen anterior end covered with fine striæ like a Pecten or Lima, while the posterior or caudal portion was filiform. The usual clear granules and vesicles were present. An elongated granular structure like a canal was occasionally visible in the central line, but this could not be traced throughout the entire length of the animal. When freed by laceration of the worm, they rush through the surrounding water very actively by aid of their cilia, for it is to be remembered they are but in their native medium, since the intestinal canal is ciliated, and often gives passage to currents of water. Although a little glycerine is added to the water, their cilia continue in active motion, and the contained globules are very distinct.

In a few specimens minute parasitic Nematode worms (Plate IX. fig. 15) were coiled at the sides of the intestine near its termination. There is a streak at the snout, and some faint central markings along the body. They appear to be undeveloped or partially developed Anguillulidæ, numerous examples of which are frequently found in *Lumbricus*.

Circulatory System.—The following observations on the circulatory system are in the main confirmatory of the investigations of M. Claparède, who added considerably to the descriptions of M. d'Udekem. In *Tubifex rivulorum* the course of the blood-vessels is very regular, and I have met with very few abnormal arrangements. There is a large contractile dorsal vessel which is thrown in the usual state of the animal into many zig-zags or figure of eight crossings, from the fibrous contractions at the septa. A ventral vessel less in calibre and paler in colour has a similar direction, but lies on the opposite side of the alimentary canal. The dorsal trunk, in conjunction with the alimentary canal, is covered by the gland-cells previously described, while the ventral is free. The course of the dorsal vessel is as follows :—

At the posterior end of the worm it is joined by the ventral (in a similar manner to that shown in Plate X. fig. 5) and proceeds forwards as a deep red trunk, the depth of its colour being, perhaps, due more to the larger calibre of the vessel as contrasted with the ventral, than to its thicker coats. In this region, moreover, it pulsates with a swift and clear stroke from behind forwards —the action being noticeable in the penultimate segment. The ventral trunk, on the other hand, so far as I could observe, remained of the same calibre at this part, except when affected by the wave of perivisceral fluid. In the stasis following the introduction of chloroform, the dorsal vessel becomes moniliform posteriorly, being constricted, apparently, by the spasm of the septal fibres; while the perivisceral corpuscles rush with great vehemence through the narrowed apertures. From the colour of the central region of the last segment, it would seem that, before joining, the ventral and dorsal vessels form a slight plexus, and, from the vigorous motions usually occurring in this part, there could be no better region for the aëration of the blood.

In each segment two great branches pass off from the dorsal and ventral vessels respectively. Towards the posterior border a large trunk (the *perivisceral*) springs on each side from the dorsal, and, proceeding outwards towards the body-wall, divides into numerous capillary branches, which again unite to form a trunk, nearly as large as the original, that on each side enters the ventral vessel. The extensive coils formed by the perivisceral branch of the dorsal provide ample freedom of motion, an arrangement so necessary during the contortions of the worm. The coils are especially distinct towards the posterior part of the body. About the middle of each segment, again, the ventral vessel on each side gives off a branch, which passes upwards round the intestine; but whether it terminates by anastomosing with its fellow of the opposite side, or by joining the dorsal, could not be determined. Certainly no branch of any size joined the dorsal in this region.

In some views there are, besides the perivisceral branch of the ventral, one or two vessels towards the anterior part of the segment, which course outwards from the ventral, and anastomose on the body-wall with branches of the perivisceral. Such a branch or branches are not strictly "intestinal," for they likewise send twigs to the body-wall. I must also add that in one specimen the ventral main trunk was observed to bend outwards in a simple curve, without being fixed in the centre by any vessel or fibrous tissue. The "intestinal" branch thus does not always attach the main trunk closely to the alimentary canal. After the addition of a little aconite (which causes spasm of the fibres at the septa, so as to render the worm moniliform) the dorsal and ventral vessels become much contracted posteriorly, while the perivisceral remain well filled, indeed, so as to constitute a broad red bar across the segment. Anteriorly some of the intestinal branches are similarly distended.

In the eighth segment the perivisceral branch is considerably enlarged, and, curving outwards and downwards, enters the ventral as a large trunk, only slightly less than at its commencement. The dorsal half of the vessel pulsates; the ventral does not. It would thus seem that the vessel, probably where fixed to the body-wall, ceased to pulsate. This arrangement constitutes the so-called "hearts" of these annelids, and in this species both contracted simultaneously. The perivisceral branches of the seventh and ninth segments acted similarly, though in a less conspicuous manner. The perivisceral vessel of the latter (ninth) segment is often noticed to give off large branches at the body-wall.

In specimens whose generative organs are much developed, the periviscerals of the ninth and tenth segments are of considerable size, but neither approach the periviscerals of the eleventh, which are enormously dilated, indeed, nearly as large as the main trunk itself. This enlarged perivisceral sends branches over the succeeding segments, sometimes as far backwards as the twenty-third in ripe animals (Plate X. fig. 6, *e*, *e*). The periviscerals of the twelfth segment under the same circumstances are also dilated, and those of the thirteenth more so, three large branches being directed forwards. The arrangement of these trunks would seem to countenance my view of the circulation in the ordinary condition, viz., that the periviscerals as a rule do not proceed as continuously cylindrical trunks into the ventral, but that they communicate by their branches on the body-wall.

Continuing forwards, the main trunks (dorsal and ventral, Plate IX. fig. 17) have the same arrangements in the fifth and sixth segments as previously described, the only noteworthy change being an occasional abnormality in the origin of the intestinals—one coming off before the other, and thus affording a better view of their distribution. It is to be observed, also, that the ventral trunk has in this region faint contractions, which render the vessel pale; it then fills again. The periviscerals of the fourth segment are somewhat smaller than usual. At a point corresponding to the posterior border of the third segment, the dorsal gives off two large trunks, doubtless the homologues of the periviscerals, though they generally slant obliquely forwards and outwards rather than transversely, and divide into many small branches towards the margin of the body. The dorsal then pursues its course straight forwards, again gives off two branches behind the mouth—the branches subdividing and inosculating with others in front and behind, and finally terminates by forking in the snout in front of the mouth. The two divisions thus formed split, after bending backwards, into numerous twigs, which unite with the capillaries that go to form the feeders of the main ventral vessel. The latter originates, by the junction of the two great branches constituted by the feeders just mentioned, towards the posterior border of the third segment. In many positions under pressure, the whole anterior part of the animal is one vast series of vascular

reticulations. The latter quite differ from the long simple coils described and figured by Dr WILLIAMS* in *Nais filiformis*, but doubtless he was misled by their complexity.

In some views, where congestion had been produced by the addition of chloroform, atropine, or muriate of morphia,† the intestine was observed to be covered by an extensive series of minute blood-vessels, longitudinal and circular. This arrangement was due to the presence of two or three vessels in each segment winding round the canal, and sending off lateral branches to meet others from the adjoining trunks, as shown on the supero-lateral surface of the intestine in Plate X. fig. 7, the ventral vessel in this case not being seen. A series of nearly parallel anastomosing branches course from the secondary trunk in a longitudinal direction. A lateral view of the seventh segment after the addition of chloroform (Plate X. fig. 8) exhibits a much coarser reticulation, in which the main trunks arise from the ventral. In such experiments, of course, the trunks do not remain of their normal calibre, but are irregularly contracted. These statements with regard to the vascular ramifications on the surface of the intestine are fully borne out in the transverse and longitudinal sections of the worm, the former exhibiting a complete mesh-work of blood-vessels surrounding the alimentary canal in certain positions. The same has been noticed by M. PERRIER‡ in *Dero obtusa*, one of the *Nais*-group, and he aptly compares the arrangement to a very elegant trellis with rectangular openings. According to Mr LANKESTER they would appear to be more easily observed in *Chætogaster*. Under the action of chloroform, also, many fine cutaneous branches were seen in *Tubifex* forming a network and a series of parallel longitudinal vessels. These ramifications remained comparatively still during the motions of the worm, and were probably fixed branches of the perivisceral. Some of the twigs (which extended over most of the body-wall) coursed towards the septa, and inosculated with the same set of vessels in the adjoining segments. There is thus a series of vascular communications between segment and segment independently of the main trunk. It would also appear that some of the branches, which proceed from the dorsal towards the ventral, do not join the latter trunk, but inosculate with twigs from the opposite side of the body.

The circulatory system in the elongated form (Plate X. fig. 9,) much resembles that of the foregoing, though it is proportionally more developed. The swollen periviscerals or "hearts" occur in the eighth segment, and pulsate vigorously and alternately from eight to twelve times per minute. Very slight contraction of the tissues anteriorly causes the mobile vessels to assume

* Report Brit. Assoc. p. 182, Pl. III. fig. 8.

† The addition of a small quantity of this drug in solution was speedily fatal to ciliary action.

‡ Ann. Nat. Hist. 4th Se. vol. 6, p. 264 (Extr. Comptes Rendus).

so many curves and spirals that it is impossible to unravel them, (*vide* Plate IX. fig. 16), until a more favourable condition of extension ensues. It is a fact of interest, that while the vascular distribution is more apparent in this species, the perivisceral corpuscles are less developed.

Generative Organs.—The first swollen segmental organ in the shorter form (*Tubifex rivulorum*), as M. CLAPARÈDE observes, occurs in the eighth segment. In one specimen the dilated portion of the organ was at the anterior border, and on the same side the coils of the duct had entered the seventh; while on the other side neither coils nor dilated portions were visible in either seventh or eighth segments, but both were present on that side in the ninth. Considerable room, therefore, exists for misunderstandings. The segmental organs (Plate IX, fig. 18, from behind the middle region,) vary a little in shape, and some in developed specimens are tinted brownish by transmitted light. The shorter tube (*a*) is attached to the septum in front, opening through the membrane by a slightly dilated and ciliated opening. The long coil, again, opens externally, also by a very slightly enlarged extremity, at a point a little posterior to the former, but in the same segment.

The sexual pore lies a short way behind the ventral bristles of the eleventh segment, and has the form of a conical papilla (Plate X. fig. 10), which is perforated at the summit. Occasionally spermatozoa are observed to issue from the tip. In this instance the copulating organ is slightly protruded.

The integuments, as already noted, from the tenth to the fifteenth segment become at the reproductive season very opaque, and hence the difficulty in making an accurate description is much increased. The tenth and eleventh segments especially swell out, and become opaque white at the period of perfection.

Male Organs.—In those with undeveloped (or only slightly developed) generative organs the testicles are found at the anterior border of the tenth segment, and the segmental organ in the eleventh is small, showing that it only becomes enlarged with the other structures subsequently. Under the same circumstances coils of the ciliated duct of the segmental organ are found at the posterior border of the twelfth segment. At a further stage of development the testicles form large opaque-whitish masses, which are at first granular (Plate X. fig. 19). What appears to be a further stage is shown in fig. 20, Plate IX., the cells being filled with a vast number of awl-shaped bodies, measuring $\frac{1}{1250}$ of an inch long, rounded at one end, and having a slender style at the other. There are also numerous minute ovoid granules in the cell, their long diameter ranging from $\frac{1}{5000}$ to $\frac{1}{6000}$ of an inch. The bodies represented in fig. 6, *b*, *c*, *d*, Plate IX., are probably also stages in the development of these structures.

In their fully developed state the spermatozoa resemble wavy or zig-zag

lines (Plate IX. fig. 21), sometimes with attached globules or loops resembling heads, but more frequently without them. They do not swim actively about on escaping through a wound, but spread themselves insensibly over the field of the microscope. They often, as M. D'UDEKEM shows, surround a sperm-cell so completely as to resemble a seed with its downy pappus.

The first testicle, in those with developed organs, occupies to a greater or less degree one side of the ninth segment; and occasionally it is little developed while the second stretches to the sixteenth segment. I have also seen the first testicle slip entirely out of the ninth segment, and lie towards the posterior part of the tenth. It is attached to the septum between the ninth and tenth segments, in the angle next the intestine (in ordinary views, *c*, fig. 6, Plate X.) In a large specimen there was the unusual appearance of a glandular organ resembling a testis with sperm-cells in the fifth segment, and the seventh and eighth had each two of a similar nature. The ninth had the vas deferens with its trumpet-shaped aperture fixed in the septum between it and the eighth. The developed organ (testis), moreover, stretched from the bulged septum last-mentioned to the fifteenth segment. The ordinary condition, however, is that the first testis occurs in the ninth segment, the receptacles in the tenth, the ovaries in the eleventh, and the second testis in the twelfth segment.

The eleventh segment also holds the large coils of the vas deferens (Plate X. fig. 6, *b*), which, moreover, often slip into the twelfth. The trumpet-shaped aperture is connected with the septum between the tenth and eleventh segments. It (vas deferens) is clearly a development of an ordinary segmental organ, as indeed most authors state.

In the sixteenth segment of one example there was a large parasite (Plate X. fig. 11) in the lobule of the testis, and extending throughout the entire length of the division. Its interior was filled with cellulo-granular matter, and in contraction its sides were distinctly crenated, while the body was crossed by transverse rugæ, like a larval cestode. There is a short median furrow passing from a notch in its anterior or smaller end. It is not ciliated.

Female Organs.—In the early condition the ovaries are observed at the anterior border of the eleventh segment, attached on each side to the septum, close to the dorsal vessel and intestine (Plate X. fig. 12, *a*, *b*). In this state they are composed of granular cells. The developed organs (sometimes of an orange colour) stretch to the fourteenth, fifteenth, and subsequent segments, and when compressed give exit to a vast mass of fatty granules.

The seminal receptacles (Plate X. fig. 6, *a*) are amongst the most distinctly marked organs in the developed animal, and are at once distinguished by the lively contractions which ensue when they are filled with spermatozoa. They occupy nearly the whole of the tenth segment, and the apertures have the form

of trumpet-shaped organs, one on each side anteriorly. When empty the sacs have a somewhat coarse granular appearance, and do not show the rolling contractions.

In a specimen with largely developed ovaries, a curious ovoid organ (Plate X. fig. 13) occurred at the anterior part of the eleventh segment, and another at the anterior part of the twelfth. Externally there was a dense capsule, and internally a minutely granular mass altogether different in appearance from the structure of the ovaries or their contents. They measured about $\frac{1}{90}$th to $\frac{1}{100}$th of an inch in diameter, and were of so unyielding a nature that they soon escaped by rupture through the body-wall of the worm.

EXPLANATION OF THE PLATES.

Plate IX.

Figure 1. Bristle and dorsal hook of *Tubifex rivulorum*, from the anterior segments. × 350 diam.
Figure 2. Ventral hooks of the same species. × 350 diam.
Figure 3. Anterior hooks (accompanyingthe bristles) of the elongated form from the lakes; *a*, processes in the fork. × 350 diam.
Figure 4. Body-wall (*a*) of *T. rivulorum*, with parasitic Vorticellæ. × 210 diam.
Figure 5. One of the parasitic Vorticellæ in a partially expanded state. × 350 diam.
Figure 6. Perivisceral corpuscles of *T. rivulorum*; *a*, cells in the ordinary condition; *b*, a cell from the perivisceral chamber after the addition of chloroform; *c* and *d*, the contents of the latter more highly magnified. In all probability, however, this (*b*) is only a sperm-cell in course of development. × 350 diam.
Figure 7. The same after the action of dilute glycerine, with extruded clear granules. × 350 diam.
Figure 8. Variously shaped corpuscles from the perivisceral fluid. × 350 diam.
Figure 9. Perivisceral corpuscles of the elongated *Tubifex* from the lakes. × 280 diam.
Figure 10. Elliptical and other corpuscles from the same fluid. × 350 diam.
Figure 11. Perivisceral corpuscles of a species referable to Claparède's genus *Limnodrilus*. × 350 diam.
Figure 12. Gland-cells from the intestinal wall of the same species. × 350 diam.
Figure 13. Ciliated epithelial cell from the interior of the digestive tract of the same animal. × 350 diam.
Figure 14. *a*, *b*, *c*, *d*. Various forms of the *Opalina* parasitic in the alimentary chamber; *b* represents an outline of the anterior end of a large specimen, the cilia being omitted. × 210 diam.
Figure 15. Parasitic *Nematode* worm from the same region. × 400 diam.
Figure 16. Anterior region of the elongated *Tubifex* from the lakes, showing the dense coiling of the blood-vessels anteriorly in the semi-contracted condition; *a*, dorsal blood-vessel; *d*, ventral.
Figure 17. Anterior segments of *Tubifex rivulorum* in a somewhat contracted and flattened condition, exhibiting the arrangement of the vascular system; *a*, fissure at the mouth; *d*, dorsal blood-vessel; *v*, ventral. The figures indicate the segments.
Figure 18. Segmental organ of the same species from behind the middle region of the body; *a*, the septum.
Figure 19. Sperm-cell in the granular stage. × 350 diam.
Figure 20. Awl-shaped bodies and granules from a sperm-cell in course of development. × 400 diam.
Figure 21. Spermatozoa of *T. rivulorum*. × 350 diam.

PLATE X.

Figure 1. Perivisceral corpuscles from *Tubifex rivulorum* after extrusion into the water. × 210 diam.

Figure 2. *a*, *b*, *c*, Various forms assumed by the parasitic larva from the perivisceral chamber of *Tubifex*. × 210 diam.

Figure 3. Granular glands from the wall of the digestive cavity *in situ*. × 350 diam.

Figure 4. Isolated gland-cells similarly magnified.

Figure 5. Posterior end of the *Tubifex* from the lakes, showing the junction of the dorsal and ventral blood-vessels; *a*, cuticle; *b*, chorion and muscular coats; *c*, ending of dorsal blood-vessel; *c'*, last perivisceral; *d*, perivisceral and other corpuscles. × about 50 diam.

Figure 6. Portion of *Tubifex rivulorum* at the reproductive season; *a*, seminal receptacle in the tenth segment; *b*, coils of ciliated duct (vas deferens); *c*, testicle; *d*, atrium (?) with a double outline under pressure; *e*, *e*, elongated vascular branches from the eleventh and other segments for the supply of the developed generative products. × 55 diam.

Figure 7. Vascular ramifications on the supero-lateral surface of the intestine; *a*, dorsal blood-vessel; *b*, septum. × 210 diam.

Figure 8. A lateral view of the seventh segment after the addition of chloroform; *d*, dorsal vessel; *v*, ventral; *p*, perivisceral. × 210 diam.

Figure 9. Anterior portion of the elongated form from the lakes, showing the circulating system; *a* dorsal blood-vessel; *b*, ventral; *c*, enlarged pulsating cavities or "hearts" of the perivisceral in action; *d*, forking of ventral vessel.

Figure 10. Tip of the copulating organ protruding through the sexual pore; *a*, hooks. × 210 diam.

Figure 11. Larval parasite from the lobule of the testis. × 210 diam.

Figure 12. The eleventh segment, showing the development of the ovaries; *a*, cellulo-granular contents; *b*, investing membrane; *c*, perivisceral corpuscles; *d*, granular glands of intestine. × 210 diam.

Figure 13. Curious ovoid structure from the anterior part of the eleventh segment of a specimen with largely developed ovaries. × 210 diam.

XIII.—*On the Place and Power of Accent in Language.* By Professor Blackie.

(Read 6th March 1871.)

On the subject of accent and quantity as elements of human speech, there has been such an immense amount of confusion, arising from vague phraseology, that in renewing the discussion nothing seems more necessary than to start with a careful and accurate definition of terms; and that a definition not taken from books, and the dumb bearers of a dead tradition, but from the living facts of nature, and the permanent qualities belonging to articulated breath. Now, if we observe accurately the natural and necessary affections of words in human discourse, considered merely as a succession of compact little wholes of articulated breath, without regard to their signification, we shall find that all the affections of which they are capable amount to four. Either (1), the mass of articulated breath which we call a word, is sent forth in a comparatively small volume, as in the case of a common gun, or it is sent forth in large volume, as in the case of a Lancaster gun; this is a mere affair of bulk, in virtue of which alone it is manifest that any word rolled forth from the lungs of a Stentor must be a different thing from the same mass of sound emitted from a less capacious bellows. In common language this difference is marked by the words *loud* and *low*. A broader wave of air impelled against the acoustic machinery of the ear will always make a more powerful impression independent of any other consideration. But (2), an equal or a stronger impression may be made on the ear by a less volume of sound, if it be sent forth with such an amount of concentrated energy and force as to compensate for its deficiency in mass. A more sharp and intense clap of thunder, for instance, may in this way affect the ear more powerfully than a greater peal less vigorously sent forth and more widely spread. The affection of sound brought into action here is what in language we generally call stress or emphasis; and it depends altogether on the intensity of the projectile force, and gives to speech the qualification of more or less forcible. But (3), this force may often be, and very naturally is, accompanied with another affection of sound altogether distinct, viz., the sound may be deep and grave, or high and sharp, corresponding to what in music we call bass and treble notes. The analogy between music and articulate speech is here so striking, that it has passed into common use; as when we talk of a person speaking in a high or a low key, in a monotone, or in a deep low sepulchral tone, and so forth. And in reference to single words, we are

accustomed to say, that the acute accent stands on syllables pronounced in an elevated tone, and the grave on those pronounced with a low tone. The only difference between the musical scale and the scale of articulate speech in this view, is that the latter, besides being much narrower in its compass, rises or sinks, not by mathematically calculated intervals, but by a mere upward or downward slide, not divided by any definite intervals. The true connection of these slides with the general doctrine of accent has been well set forth by Mr WALKER, the author of the Pronouncing Dictionary, in a separate treatise.* (4). The fourth affection of articulated sound is that which is familiarly known to scholars and schoolboys under the name of quantity, and signifies simply the greater or less duration of time during which the sound continues to impress the ear. For it is manifest that any sound may be produced either by a sudden stroke, or jerk, or by a traction prolonged to any extent. In grammar a short vowel corresponds to a quaver or semiquaver in music, and a long vowel to a crotchet or minim, according to the ratio of the movement.

Now it should seem to be pretty plain at the outset, to all persons whose ears have been exercised in a very slight degree to discern the differences of articulate sounds, that what is called accent in grammar has to do only with the second and third of the above four elements, and not at all with the first or fourth; in other words, that the accent of a word is totally distinct both from the volume of voice with which the word is enunciated, and the length of time during which the speaker dwells on the syllable. Nevertheless, such is the confusion which learned writers have introduced into this subject, that it is necessary at the very outset to enter a *caveat* against a very prevalent notion that the placing of the acute accent on a syllable, naturally or necessarily implies a prolongation of the sound of the accented vowel; or, in other words, that to accent a syllable withoutmaking it long is impossible. In music no performer ever dreams that the rhythmical beat on the first, we shall say, of three quavers—that is jig time—necessarily turns the quaver into a crotchet. A musician making such an assertion would simply be deemed drunk or mad; nor does it make the slightest difference in the quantity of the note receiving the musical accent, whether in respect of elevation of tone it stands high or low in the scale. It is understood by every girl who fingers the piano, that the elevation of the note, the duration of the note, and the rhythmical emphasis upon the note, are three essentially different things which never interfere with one another. But the moment we transfer this case to the analogous domain of spoken accent,—the *certus quidam dicendi cantus*, as CICERO called it,—we find ourselves involved in a region of confusion and contradiction with regard to the simplest matters, than which few things can be imagined more humiliating to human reason. For however diver-

* A Key to the Classical Pronunciation of Greek and Latin Proper Names; with Observations on the Greek and Latin Accent and Quantity. By JOHN WALKER. London, 1827.

gent the printed opinions of the learned may sound, that the relative facts are exactly the same in the case of spoken speech, as of song or played notes, is beyond question. A single example will make this evident. The first syllable of *pō′-tent*, for instance, according to a well-known rule in the English language is long; but the first syllable of the Latin word from which the English comes is short, *pŏt′-ens*, while the accent is on the same syllable in both languages. Now, it surely will not be alleged, in obedience to the dictates of any sane ear, that in pronouncing the Latin word I am obliged to call it *pō′-tens*, after the English fashion, on account of the tyrannic force of the acute accent. It seems, nevertheless, that British schoolmasters and professors have acted under the notion that some compulsion of this kind exists; for as a rule they say *bō′-nus*, and not *bŏn′-us*, though they know very well that the first syllable of this word is not long, as in the English word *pō′-tion*, but short, as in *mŏr′-al*. Such confusion of ideas on a very simple matter is a phenomenon so strange, that some reason may justly be demanded for its existence; and on reflection I find two reasons principally that seem to account for it. The first is the confounding of a really long quantity with that predominance of a sound to the ear which is a necessary element of all accentuation. Thus, when I take the word *tĕp′-id*, and form the abstract substantive from it—*tepĭd′-ity*, by changing the place of the accent from the first syllable of the adjective to the second, I certainly have given a prominence to the short *i* which it did not possess before, and a prominence, no doubt, which though it consists principally in force, emphasis, or stress, may also carry along with it a certain dilatation of the tenuous vowel, so that it is really longer in the substantive, being accented, than when it was slurred over without emphasis in the adjective. But though this is quite true, it is altogether false to say that the vowel has been made long according to the comparative value of prosodial quantity; for, if the second syllable of *tepĭ′d-ity* be compared, not with the last syllable of the adjective *tepid*, but with the same syllable of the substantive, as mispronounced by some slow, deliberate Scot—*tepī′-dity*, *tepē′e-dity*—we shall see that the vowel *i*, for all rhythmical purposes, still remains short. The other cause which presents itself to explain the confusion of English ears on this subject, is the doctrine of what the Greek and Roman grammarians call length by position. According to this doctrine, a vowel before two consonants is long. What this means we may clearly conceive by the example of such words as *gōld*, *ghōst*, in English, or *Pābst* or *Ōbst* in German; but though the vowels in these words are unquestionably long in both languages, they are so only exceptionally, the rule both in English and German being that a vowel before two consonants is short. Of this rule the word *shŏrt* itself may be taken as an excellent example; which, if it occurred in a Greek chorus, by the law of position, would be sung *shōrt*, with the *o* prolonged, like *o* in *shore*. Now, with this classical analogy in their ears, or rather in their

head (for it is by no means certain that all those authors who have written on this subject did use their ears), when I pronounce such a word as *prĭm′-rōse* or *ĕl′-bōw*, it is not at all uncommon for English scholars to say, and obstinately to insist, that the accent on the first syllable of these words is necessarily accompanied by a prolongation of the vowel. But this is a judgment of the question, not by the living fact of the sound, but by the doctrine of an old book about the sound. And as to what the old book says, we in fact do not know whether length by position meant a habitual prolongation of the vowel sound in common discourse, as in our words *gold, told, sold, ghost, most*, or only a poetical license; that is to say, whether the genitive plural of ἀνήρ, of which the penult is short, was really pronounced *awndró′ne* or *ăndrōne* in prose. I for one am strongly inclined to think that the latter is the true fact of the case; for, if it had been otherwise, would it not have been a more correct phraseology in the grammarian to say, that a vowel before two consonants is naturally long? But when they tell us that a vowel which is naturally short becomes long when two consonants follow, this looks rather like an artificial exception than a natural rule. And I am inclined to think that such an exceptional rule was introduced from sheer necessity, like the long *o* in certain comparatives, such as σοφώτερος, because, without such a license, really long syllables in sufficient abundance would not have been found in the language for the necessities of the early dactylico-spondaic poetry. As to any inherent natural necessity in the rule, such an idea cannot be entertained for a moment; for the vowel is then most easily prolonged—as in the English words *pō′-tent, nō′-tion, na′-tion, pā′-tent*, where it is kept separate in spelling from the influence of the succeeding consonant or consonants, which, as in *pōr′-tion*, rather act by cutting the breath short, and preventing the prolongation of the vowel. The influence of the consonant in shortening the vowel will be apparent in comparing the words *nŏm′-inal* and *Lēb′-anon* with *nō′-tional* and *lā′-bial;* nor does the addition of a second consonant in any perceptible way alter the case. If the first syllable in *prĭm* is manifestly short, it is certainly not made long by the addition of the long syllable *rose* in the noun *prĭm′rōse*—a word which, in the relative values of its final and penult syllables, corresponds exactly to a whole host of Greek words which usher in a long final by a short accented penult, as in Πλάτων, the name of the great philosopher of Idealism, in Anglicising which, we, besides attenuating the vowel, elongate the short penult, according to the practice of our own language.

It will now be distinctly understood, as a starting-point to the present inquiry, that by accent I mean merely a certain predominance, emphasis, or stress given to one syllable of a word above another, in virtue of a certain greater intensity of force in the articulated breath; this increased intensity being naturally in many cases, but not necessarily in all cases, accompanied by an elevation in the key of the voice. My observations do not include either rhetorical accent,

which affects whole sentences and clauses, or national accent, which, in addition to rhetorical accent, often includes some favourite sound, note, or vocal mannerism characteristic of different peoples.

The general question to which we shall now attempt a scientific answer is the following—What are the great leading principles on which accent, as a phenomenon of articulate speech, depends? Are there any such principles, or is it a matter of mere arbitrary association, fashion, and habit? and in the comparison of different languages what is the standard of value in respect of their accentual character? Does æsthetical science contain any general rules which might enable us to measure the value of accents, as we do the value of sounds in language, when, for instance, we say that Italian is a more harmonious language than Gaelic, and Greek a more euphonious language than Latin? In answering this question, I would remark, in the first place, that there is no such thing as a language altogether without accent; only a machine could produce a continuous series of sounds in undistinguished monotonous repetitions like the *tŭm, tŭm, tŭm* of a drum; a rational being using words for a rational purpose to manifest his thoughts and feelings, necessarily accents both words and sentences in some way or other. When, therefore, we find it stated in Adam Smith's Essay on Language, and other English writers, that the French have no accent in their words, this is either a gross mistake, or it must be understood to mean that the French do not give such a decided and marked preponderance to one syllable of the word as the English do; which is very true, as any man may see in comparing the English *velocity* with the French *velocité.* But this is merely a difference in the quantity and quality of accent, not a contrast betwixt accent and no accent. The second postulate of all rational discussion on this subject is, that the significant utterance of articulate breath, like every other manifestation of reason-moulded sense, is a part of æsthetical science, and subject to the same necessary laws which determine the excellence of a picture, a poem, or a piece of music. No doubt in the enunciation of words, as in all the fine arts, fashion may often prevail to such an extent, as in some cases to usurp the place of reason and propriety; but the prevalence of false taste in any department of art does not effect the certainty of the eternal principles by which it is regulated, any more than the prevalence of murders or lies amongst any people can take away from the essential superiority of love to hatred, and of truth to falsehood in all societies of reasonable beings. We are, therefore, justly entitled to look for a standard of excellence in the matter of orthoepy, no less certain than the standard of truth in morals or mathematics; as, indeed, all things in the world being either directly or indirectly the necessary effluence of the Divine reason, must, in their first roots and foundations, be equally rational and equally necessary. Now, in looking for the necessary conditions on which the

comparative excellence of accentual systems may depend, we find that they may be reduced to the four following heads :—

1. Significance.
2. Euphony.
3. Variety.
4. Convenience.

And first, that SIGNIFICANCE must be a main point in all accentual systems, is manifest from the very nature of accent. For why should a man give predominance to one syllable in a word more than to another, unless that he means to call special attention to the significance of that syllable? Nay, it may often be essential to the effect intended to be produced by the word, that its most significant syllable should be emphasised—as when Lord Derby lately said that the adoption of the Prussian system of making every citizen a soldier, would not be a *prógression* but a *rétrogression.* No doubt, in order to express such an accentual contrast as this, the English language departs from its usual fashion of accenting these words; but this only proves that the English method of accentuation in this case is a mere fashion, founded on no natural law, and which accordingly must yield to the higher law of emphatic significance, when nature, like murder, will out. And here we may observe that the English, as a merely derivative and mixed language, is by no means a favourable one for exhibiting the natural and normal laws of a rational accentuation. Neither, so far as I know, is there any language whose orthoepy presents so many anomalies, and where changes entirely reasonless and arbitrary, require only the stamp of aristocratic or academic whim to give them currency. With regard, however, to the natural preponderance of the contrasting element in compound words, the Saxon part of our language affords obvious examples of its recognition, as, when we say, *out'-side* and *in'-side, back'-wards* and *for'-wards, up'-hill* and *down'-hill, male* and *fémale.* So in the names of the Highland clans, as *MacBain, MacDonald, MacGrigor,* &c., the emphasis does not lie on the common element, the *Mac,* but on the distinctive element to which the other is attached; and in this view our Saxon pronunciation of *MácIntosh* and *MácIntyre,* affords two very good examples of words where custom and fashion have inverted the natural and significant place of the accent. In the Greek language, this most natural of all accentual laws, operates in all such compounds, as ἄκαρπος, ἄπαις, σύνοδος, πάροδος, with which we may contrast the English *fruitless, childless,* where the accent is on the root, and not where it ought naturally to be on the contrasting element of the compound. In the same category with this I am inclined to place the accent on the augment in Greek, as in ἔτυψα, τέτυμμαι; for it is the augment here manifestly that contains the element of past time which is distinctive of the tense, being equivalent in effect—whatever its original meaning may have been—to *I* DID *strike,* as opposed to *I am striking.* The same desire to call attention to the distinctive element may have determined the Greeks to

accent the penult of all diminutives, contrary to their usual practice in words, with a short final syllable, as in παιδίον, παιδίσκος, κ.τ.λ.

Under this head I am sorry to record my dissent from a German writer of acknowledged excellence on this subject—Dr KARL GÖTTLING.* This learned writer lays down the maxim in the first place, that in the Greek language the accent falls on the syllable containing the principal idea of the word; and, accordingly, he says that in λέγω and other verbs not pure it falls on the penult, because this syllable is the root, and the root, as containing the principal idea of the word, is naturally emphasized. Now, looking back to the first framers of a language, I cannot see in this case any reason why the root syllable should have received the accent rather than the termination, which, for the sake of distinction and contrast, is added to the root. If we say ἄκαρπος, because we wish to call attention to the negative particle, why should we not say λεγώ calling attention to the personal pronoun; as, in fact, we do say in English, *quoth I', quoth* HÉ? And in the same way with regard to nouns, as the terminations of the cases were originally expressions of relation, attached to the noun for the sake of emphasis and contrast, I do not see why the schoolboy fashion of declining *dominús-í-ó'-úm*—should not have been the original one. And so in the case of the German *brauer*ÉI and the Scotch *brewer*ÉE as contrasted with the English *bréwery;* for though no doubt it may be said, that as the root *brew* contains the principal idea, the accent should naturally be there, and this is what GOETTLING says, yet it may with more right be said, that what is intended to be emphasized here is not mere brewing, but a place for brewing, and that the syllable denoting the place receives the accent as appropriately as the terminations ήριον, εῖον, and ών, when used for the same purpose in Greek. Only so much truth, therefore, can I perceive to lie in GOETTLING'S principle, as to admit that, so soon as the original signification of terminations is lost, and people commence to supply their place by prepositions, pronouns, and other separate words, whose significance is felt—then, and not till then, can the accent on the root syllable be regarded as natural and normal in language. Thus, when the German says *Hābe,* laying the stress on the first syllable of the first person singular present indicative of the verb to *have,* it is natural and normal, because the termination *e* has no significance to him, and could receive an accent only from a senseless fashion, not from a natural propriety. On the other hand, in *A'bgābe, Híngābe, Zúgābe,* and similar compounds, the accent is properly placed on the contrasting element of the compound, of which the significance is strongly felt.

The next element we have to take into consideration in measuring the value of different accentual systems is EUPHONY. The simple mention of this word will suffice to show how very one-sided a notion it was in GOETTLING, that the

* Elements of Greek Accentuation, from the German. London: WHITAKER. 1831.

accent, as a general principle, should always be on the root syllable, as being the most significant. If man were only a logical animal, this might be all very well as an *a priori* ideal of a perfect accentual system; but he is also, if not always at starting, certainly when fairly developed, an æsthetical animal, who may be allowed on occasions to sacrifice the significance of ideas to the luxury of sounds. And if this is true of man generally, it is certainly so *a fortiori* of the Greeks, whose whole culture grew out of music, and remained in the closest connection with it to the very end of their classical period. Supposing, therefore, that with this most musical and artistic of all peoples a regard to the mere luxury of sound had, in certain cases, determined the position of the accent, let us ask in what way this determination would naturally manifest itself? The answer is obvious. In richly terminational languages such as the Greek, where the terminations are not insignificant little short vowels or syllables as in the German *Gabe, Buche, Brüder,* &c., but deep, full-rolling, prolonged vowel-syllables such as ων, οις, αο, αων, and οιο, there might exist a very natural tendency to place the accent on these syllables,—not, of course, because there is any necessary connection, as some persons say, between accenting a syllable and lengthening it, but because when a syllable by the presence of a long vowel actually is long, the placing of the accent on it, is the most certain way both to bring out the full length of the vowel, and to ensure the permanence of the full musical value of the syllable, so long as the language lasts. For whatever other syllables of a word may from carelessness, or haste, or reasonless fashion, be cheated of their natural quantity, the accented syllable will always most stoutly maintain its rights, even if it be a short syllable, much more if it be a long. To illustrate this by a familiar example; in the famous Homeric line (Il. i. 49), in which the twang of Apollo's bow is described:—

"δεινὴ δέ κλαγγὴ γένετ' ἀργυρέοιο βιοῖο,"

it is manifest both that the euphony of the line lies mainly in the two terminations in οιο, though these syllables are certainly not the significant ones in the verse; and further, that this verse is much more beautiful when recited with the rhythmical accent on both the full-sounding penults, than when, according to the prose accentuation, it emphasizes only the οῖ of the last word. The coincidence of the termination with the accent therefore is favourable to music; and it is favourable also as a bar to the injury which time is always ready to inflict on final unaccented syllables. Now, with this principle to guide us, we shall have no difficulty in seeing the cause of one peculiar excellence which the ancient Roman critics recognised in the Greek, as contrasted with their own tongue, in respect of the accentual system. For, as the Romans in no word placed the accent on the last syllable, it followed that they could enjoy the rich auricular luxury of a grand terminational unison of accent and quantity, only in the case

of words whose terminations are dissyllabic. Thus, they dealt largely in final trochees—trochees both by accent and quantity, in such words as *sermō'nis, pennārum, domino'rum, lēgis, probā'vit, voluptā'tem,* and so forth, but could not say *dominō's,* or *Macenā's,* or any word accented in the same way as in English our *enginéer, voluntéer, eváde, capsi'ze, theori'se.* On the other hand, the Greek terminational accent is pretty equally divided between trochaic terminations, such as οἷο, φιλοῦσι, τυφθεῖσα, μῦθος, σῶμα, μᾶλλον, and oxytone endings, such as ἀγαθῶν, λαβών, τυφθείς, φιλεῖς. Of the prevalence of the oxytone accent in Greek, especially in large groups of adjectives and substantives, not to mention the whole army of prepositions, and certain familiar parts of verbs, any one may convince himself by taking a sentence at random from a Greek book; and the effect of this on the music of the sentence will be evident to the dullest ear. Sometimes a whole sentence runs on with a succession of accented terminational syllables, a peculiarity which, without any rhetorical intention, arises naturally from the number of oxytone substantives and adjectives, and the additional fact that all substantives of the first declension, whatever the accent of their termination may be, receive a long rolling accent on the last syllable of the genitive plural, while all monosyllables of the third declension, by a law common both to Greek and Sanscrit, transfer the accent from the radical syllable to the termination in the genitive and dative cases of both numbers. Take a passage from Plato's Republic as an example:—

"Οἵ τε θηρευταὶ πάντες, οἵ τε μιμηταί, πολλοὶ μὲν οἱ περὶ τὰ σχήματά τε καὶ χρώματα, πολλοὶ δὲ οἱ περὶ μουσικήν, ποιηταί τε καί τούτων ὑπηρέται, ῥαψῳδοί, ὑποκριταί, χορευταί, ἐργολάβοι, σκευῶν τε παντοδαπῶν δημιουργοί, τῶν τε ἄλλων καὶ τῶν περὶ τὸν γυναικεῖον κόσμον, καί δὴ καὶ διακόνων πλειόνων δεησόμεθα. ἢ οὐ δοκεῖ δεήσειν παιδαγωγῶν, τιτθῶν, τροφῶν, κομμωτριῶν, κουρέων, καὶ αὖ ὀψοποιῶν τε καὶ μαγείρων; ἔτι δὲ καί συβωτῶν προσδεησόμεθα."*

Greek, therefore, is superior to Latin in this respect, just as an instrument with a larger is superior to one with a smaller compass of notes. And taking Italian, under this point of view, into the comparison, we observe that the few oxytone accents which that beautiful language possesses all arise out of Latin words, with an accented penult, whose last syllable has fallen away; thus, *podestá* from *potestate, amó* from *amavit,* and so forth. The same is the case with the French, as in *velocité, varieté, valeúr;* and most of our English oxytones, whether Latin or Greek, are merely curtailed forms of a final trochaic accent, as *eváde* from *evádo, volunteér* from *volontiē're, proceed* from *procē'do, theorise* from θεωρίζω. And it is this systematic curtailment by the way, caused by the dropping of the final unaccented vowel both in Latin and Saxon words, which has produced that lamentable deficiency in trochaic endings which makes our rhythmical language so much narrower in compass than that of Greek,

* Rep. ii. 373, B.

Latin, German, and Italian. Only for short lyrical efforts can we manage the rhymed trochaic ending with graceful effect; all attempts to go beyond this natural limit have ended either in a manifest artificial strain, or an admixture of the comic element which is fatal to the effect of serious composition.*

If this rich and various disposition of the accent on terminational syllables is thus manifestly a plain element of euphony, that accentuation, on the other hand, will be justly esteemed cacophonous which, by drawing the accent back to the beginning of the word, that is to the third, fourth, or even fifth syllable from the end, has a tendency to cheat the ultimate or penultimate syllable of its full musical value; we say a tendency, because it is only in this tendency that the evil lies; for, if by careful elocution the tendency is corrected, the blot may be turned into a beauty on a principle to be mentioned under the next head.

The remark here made is a very serious consideration for us English, as our predominant accent is decidedly antepenultimate, and the fashion seems to be increasing of throwing back the accent from the penult to the antepenult, and from the antepenult sometimes to the fourth syllable from the end. Thus we used to say *contem'plate* and *illústrate*, whereas we say now *con'template* and *íllustrate*, *dispútable* has become *dísputable*, and *contem'plative*, of course, must become *con'templative*. The tendency of this practice to deprive our syllabification of its natural melody is obvious enough. In such words, for instance, as *sig'nify* and *púrify*, the tendency to rob the final *y* of its natural long quantity is strong, while in *cō'lumbīne*, *brō'gardīne*, from the fuller quality of the final syllable it is less. But if the danger be great in the case of the final syllable of such words, it is greater in the case of the penult, that is, the syllable immediately following the accented antepenult; for, in the case of the final syllable, a secondary accent may come in to save the prominence of the vowel, while the long unaccented penult lies under the double disadvantage of a sinking inflexion and a feeble stress, after the combined force, it may be, of an elevated accent and a long quantity. From this cause it is that in vulgar speaking the second syllable of the verb *ĕ'dūcate* is so liable to be shortened and turned into *ĕ'dĭcate;* and so strong is this tendency, that many English scholars will tell you that to pronounce the Greek word ἄνθρωπος, with the accent on the first syllable and the second syllable long, is impossible; and it is no doubt true that it is not so easy as saying ἄνθροπος, which the modern Greeks generally do; but as to the alleged impossibility, we have only to look to such words as *lan'dholder*, *coál-heāver*, *corn'deāler*, to see that it exists only in the unpractised orthoepic organs of the objectors. Of all languages that I know, the Gaelic is that whose euphony has suffered most from the habit of throwing the accent back to the beginning of the word. Of this there cannot be a more striking instance than words com-

* This is one among half-a-dozen reasons for the general want of success in our English hexametrical experiments.

pounded with the element *mōr*, signifying *great*, which may be divided into two classes, those in which the termination *mor*, recognised in its full significance, is accented, and those in which it falls under the category of the German *lich* and our *y*—in *Glücklich* and *lucky*—being used for flexional purposes without a distinct appreciation of its meaning, and therefore naturally unaccented. Of the one class of words, *Liosmō'r* and *Ben Móre*, i.e., *large garden* and *great mount*, may serve as familiar examples; of the other, *sultmhor*, *fat*, pronounced *svltur*, and *grasmhor*, *gracious*, pronounced *grásvur*, are excellent illustrations. For in these two last words we see that the adjective *mór*, in losing its separate significance, loses both its quantity and its natural accent; and the compound word becomes a paltry pyrrhic ⏑ ⏑, instead of a respectable iambus, ⏑ –́, or a majestic spondee, — –́.

Under this head it only remains to mention the extraordinary theory of Bopp with regard to the place of the accent both in Sanscrit and Greek. That illustrious philologer, in a work entitled "System of Comparative Accentuation, or concise Exhibition of the Points of Agreement between Greek and Sanscrit in the Doctrine of Accent, Berlin, 1854," lays it down as a ruling principle, that the most perfect kind of accentuation generally, and that which prevailed originally in the Sanscrit language, was that in which the acute intonation is placed as nearly as possible to the beginning of a word, however long. Into the historical proofs of any such system of accentuation ever having existed, of course only a profound student of the Vedas could enter. I am authorised, however, by Professor Max Müller and Professor Aufrecht to say, that the theory of Bopp is universally recognised as baseless; and this is just what might have been expected. The mere assertion of such a principle to a man whose ears have been trained to a rich and various orthoepy is monstrous. If the accentuation of the first syllable, as in the well-known case of the Greek vocatives of the third declension, Πάτερ, Ἄπολλον, and such like, may well be explained by the eager energy with which the call was made; it does not therefore follow either that eager energy is the only thing to be looked at in a good orthoepy, or that such oxytone words as ἀγαθή and θεός may not be so enunciated as to carry an intense expression of energy to the ear of the hearer. Let this notion of Bopp, therefore, stand as only another instance of the great blunders to which great wits are subject, and which, as large experience teaches, are the natural consolation of the dunces.

That variety is a necessary element of all æsthetic presentation of the highest order, needs no special proof. Variety is both an indication of wealth and a preventive of monotony; and as such is no less a natural source of delight to the recipient of æsthetic pleasure than of just boast to the producer.

Alles in der Welt lässt sich ertragen,
Nur nicht eine Reihe von schönen Tagen

says Goethe,

and what the Weimarian sage here says of beautiful days, is equally true of beautiful verses or of beautiful words. Hence arises the sure canon—

That language is superior in point of accentual effect which gives no partial predominance to any one accentual place, but gives the rising inflexion free play over all the syllables of a word, so far as the range is consistent with a full vocalisation. Now, when we compare the Greek and Latin language by this rule, we find a decided and universally admitted superiority in favour of the Greek; for this language admits of the acute on any one of the three last syllables, while Latin allows it to fall only on the penultimate and the antepenultimate. English, on the other hand, in this view, asserts one point of decided superiority over both the classical languages; for words so accented as *lámentable* and *héritable,* on the fourth syllable from the end, are not at all uncommon with us, while the Greeks and Romans, who had no such accents, fell into the very natural error of thinking that they were contrary to nature. But, though with help of this peculiarity we are able to marshal a much larger army of what the ancients called proceleusmatic feet in words than either Greeks or Romans, we have gained this small advantage at a great risk in point of general weight and majesty; and we may be thankful to the graceful pedantry of our classical scholars, who, in retaining the penultimate accent of many Latin words, have done something to balance our habit of flinging the principal accent far back and skipping over the remaining part of the word. The next canon deducible from the test of variety is, that of any two compared languages that is the more rich and beautiful in respect of accent, in which the acute accent is placed not on the long syllable but on the short, so that, while the accent gets fair play in one syllable, the quantity stands out in another, and thus a richer and more various melody is distributed over every part of the word. For this reason such words as *cólumbīne, rénegāde,* are more beautiful than *glō′rioŭs* and *victō′rioŭs, enginē′er* and *voluntē′er,* because in these last words, whether oxytone or proparoxytone, all the wealth of sound is spent upon one syllable, while the others remain comparatively weak and ineffective. On the same principle the Greek ἄνθρωπος is richer than the same word accented in the Latin way, ἀνθρώπος, and Ἀριστοφάνης is more beautiful than *Aristóphanes,* if, as the English habit has generally been, the final *es* of the word is pronounced short.

On the fourth principle, by which the comparative excellence of accents may be determined, I place very little value. No doubt, as languages, like buildings, are intended for use, convenience as well as theoretic excellence must be consulted; but as utilitarian considerations have changed many an architect's noble plan for a great building into a grand incongruity, so considerations of mere convenience have spoiled many a fine language. For convenience, really, in a great majority of cases, means haste and carelessness, or sloth and laziness, and in all such cases proves eventually a hostile and destructive force acting

against all excellency of organism in articulate speech. We shall only say generally, therefore, that it is always an imperfection in language when words are so accented as to produce a lumbering unwieldy heaviness in the march of syllables; and we may say also that accents ought, if possible, to be so placed as to admit of suffixes or prefixes being added without changing the intonation of the word. In this view, *contem'plative* is a more convenient accentuation than *con'templative*, because it admits of a substantive *contem'plativeness*, and an adverb *contem'platively*, being formed from it, without the necessity of either advancing the accent or allowing it to remain on the fifth syllable from the end of the new word, where its influence on the following syllables must naturally be feeble in proportion to their remoteness from the point of vocal energy.

Of the effect of fashion and whim and caprice, in determining the accent of certain words, and even of whole classes of words, contrary to every principle whether of significance, euphony, or convenience, I say nothing, because such arbitrary freaks belong not to the domain of scientific knowledge, and are merely noticeable as casual aberrations or monstrosities.

Such are the grand principles of the general doctrine of accents, so far as I have been able to discover them. It will be observed that they are based on a wide induction, and apply to Latin and Greek as well as to Gaelic or Italian. It is, however, a point which has been long maintained in the learned world, that the Greek accents have something altogether peculiar, and not peculiar only, but peculiarly mysterious about them, which prevents them from being used along with examples from any modern language as illustrations of general propositions about accent. It is against this notion—a notion peculiarly English, and prevalent in high quarters—that I must proceed now to make a distinct and deliberate protest; for, till it be removed, it will be impossible to say a single sensible word on the doctrine of accents, from which the most interesting language in the world shall not be withdrawn as an example. I proceed, therefore, to show, both from the nature of the case and from the most authoritative evidence, that there is not the slightest ground for the imagination that accent in the classical languages meant anything substantially different from what it means in English, or Italian, or modern Greek; and, as a natural sequel to this, I will trace the long course of scholarly opinion on the subject, from the doctrine of Erasmus to that of Professor Munro, Mr Geldart, and other English scholars; and conclude by showing practically, what I have proved in the actual work of teaching, how all the strange contradictions of this singular controversy can be reconciled, and all the imaginary difficulties be made to disappear.

As a foundation for all argument on this subject, we may assume—what no well-instructed scholar in the present state of learning will question—that the accentual marks now seen in every Greek book were first invented by Aristophanes of Byzantium, about 250 B.C., for the very same purpose that the marks

of emphasis stand in our pronouncing dictionaries, viz., to ensure a correct orthoepy in the reading and recitation of the language. The assertion once boldly flung forth by the early opponents of Greek accents, that they were properly marks of musical intonation, having nothing to do with spoken eloquence, can now be hazarded by no philologer. Whatever the accents meant, they were intended to direct the reading of prose; had they been anything else indeed, it is impossible to understand how they ever found their way into the familiar notation of prose. But for the sake of those who may not be familiar with the evidence on which this point rests, we shall here set down the testimonies of two eminent grammarians: first, Dionysius Thrax, who lived at Rome about 80 B.C., and whose *τέχνη γραμματική*, quoted by Sextus Empiricus (*Adv. Math.*, i. 12), has been recently printed in the second volume of Bekker's Anecdota (p. 629). This grave authority tells us that the art of grammar, as it was then practised, consisted of six parts—

1. *ἀνάγνωσις ἐντριβὴς κατὰ προσῳδίαν*—assiduous reading, according to accentuation.

2. Explanation of the meaning, according to the significance of the tropes used by the writers.

3. Explanation of the historical facts and of the glosses or peculiar words.

4. Etymology.

5. Consideration of linguistical analogies.

6. A critical appreciation of the work expounded, in its beauties and defects.

Now, there can be no doubt here as to what *προσῳδία* means; for, though the plural of this word sometimes is used in a wider sense, as we talk of the Hebrew points, so as to include aspirations, pauses, quantities, and every affection of which spoken and written words are capable, when used in the singular as a special technical term, it signifies accent, and nothing else. The second grammarian whom I quote is Theodosius, who lived in the time of the Emperor Constantine, and whose treatise on grammar was published by Goettling in the year 1822. This author, in the chapter (p. 58) entitled *πῶς χρὴ ἀναγιγνώσκειν*, says that good reading consists in three things—

1. *ὑπόκρισις*, dramatic expression, arising out of a sympathetic conception of character.

2. *προσῳδία*—or reading *κατὰ τοὺς ἀκριβεῖς τόνους*—according to the exact accents—*προσῳδία γὰρ ὁ τόνος*—for accent and tone, are the same.

3. *διαστολή*, attention to pauses and punctuation.

Now, if any person further inquires whether the ancients did not read their prose according to quantity also, I answer that of this there can be no doubt; but that the prominence in correct reading is naturally given to accent, because quantity is the specialty of poetry, and unless where we talk specially of poetry, by the word reading we are understood to mean prose. But that correct read-

ing of prose included quantity also, is evident from what the same grammarian says a sentence or two below, viz., that under προσῳδία, in a wider sense we understand both accent and quantity, and in this wider sense correct prosodial reading arises ἐκ τοῦ παραφυλάττειν τοὺς τόνους καὶ τοὺς χρόνους, from observing the *tones and the times*, and all the other affections of articulate speech. Now, as there was an uninterrupted succession of grammatical teachers, from the age of the Alexandrian Ptolemies to the time of the Roman Emperors, and from the establishment of the Eastern Empire by CONSTANTINE to the taking of Constantinople by the Turks, no historical fact can be more certain than this, that the living accentuation with which Greek was spoken in the great seats of learning and culture in the third century before Christ, and by which a just ortheopy in reading was determined, has been handed down to us in an unbroken chain of the most authoritative testimony. If this is not true, there is nothing now credited in the wide sphere of linguistic tradition that rests on a surer basis.

If, then, the ancient Greeks both spoke and read by the rule of those accents which we now see on our printed books, what are we to understand by that accent? Now, here the field of definition is happily well narrowed. That Greek accent did not mean quantity, every page of tradition on the subject distinctly testifies; that it did not mean mere volume of mass of articulate sound is equally certain; and no man, ancient or modern, ever dreamt that it did. There remain, therefore, under which it may fall to be subsumed, only the other two affections of articulate speech with which we started, viz., elevation of tone and intensity of utterance. Greek accent must be either the one or the other of these, or both together. That it means the first, viz., elevation of tone, is plain from the mere terms ὀξὺς and βαρὺς, *sharp* and *heavy*, or *high* and *low*, by which the two familiar accents are designated. It is also distinctly stated by both Greek and Roman grammarians that accent implies change of tone in the voice, by alternate elevation and depression. The phraseology, indeed, of this matter was borrowed by the grammarians from the musicians, and had reference to the high and low notes in the musical scale, these minute speculators having justly observed that, as the voice in music rises or falls by a series of measured intervals, so in articulate speech it rises and falls by a succession of slides, what our great orthoepic teacher calls the rising and falling inflexions. Either, therefore—the acute accent of the Greeks, which is the accent properly so called—means the rising inflexion of the voice on particular syllables of a word, or it means this, *plus* a stress or emphasis on a certain syllable of a word, produced by the greater force, or stretch, or tension of the voice on that particular syllable. Now that it does not mean elevation of the voice merely, but also, and at the same time, that greater stretch or tension of the voice which produces the emphatic syllable of a word, will, I think, be evident from the following six considerations:—

1. From the natural difficulty of elevating the voice, and not at the same time giving an increased emphasis to the elevated vowel; or, may I not say, rather the natural impossibility—for, though it is certainly possible to give a great emphasis to a syllable, and keep the voice at a low key, that is to say, though stress does not necessarily imply elevation—it certainly does not seem very natural or very easy to raise the pitch of the voice without accompanying that high pitch with a certain emphasis. I may, for instance, pronounce the Greek word *ἀνατολή*, with a stress on the last syllable, and yet with the whole pronounced in monotone; but, if I raise my voice on that syllable, it will be difficult for me to withhold from the syllable the stress which naturally accompanies the act of elevation.

2. But that Greek accent implies stress as well as elevation is manifest from the natural and obvious meaning of the terms used by the grammarians in describing the phenomena of accent. For what does *τάσις* mean but *stretch* or *tension?* and is it not quite plain that as contrary as light is to darkness, so contrary is *ἐπίτασις* to *ἄνεσις*,—*i.e.*, *intension* to *remission*, *strain* to *slackness* of sound—the constant phraseology of the grammarians with regard to this matter. The word *κροῦσμα*, also signifying *beat* or *strike*, which is sometimes used, of the acute accent,* sufficiently indicates its analogy to the emphatic note in a musical bar, which certainly does not signify elevation or depression.

3. The analogy of the *ictus metricus* in rhythmical composition, suggested by the word *κροῦσμα*, supplies another argument to prove that the Greek and Roman accent meant stress as well as elevation. For there are some places in the poets where we can observe that a word naturally short is made long for no other reason that can be seen than that the spoken accent on the syllable favoured the poetical license, just in the same way that the rhythmical accent sometimes does. Mere elevation has no effect on quantity; but stress or emphasis can easily be so manipulated by the voice as to pass over into a long syllable, or, to use the language of the grammarians, *ἐπίτασις* may become *ἔκτασις*, *intension* may spread itself out into *extension*.

4. That the acute accent meant stress is plain from the inherited intonation of the modern Greeks; for accent is one of the most obstinate affections that belong to spoken speech; and no man can hear such words as *καλό παιδί*, *Σκοπό*, and *Παρνασσό* in the mouth of the living Greeks without feeling that the dead mark on our books has here received its living interpretation; and, if any person objects that the modern Greek not only acutes the last syllables of these words, but makes their quantity long, this is all in favour of my argument; for the length arose and could arise naturally only from an exaggeration of that tension of voice which was the necessary accompaniment of the accent.

* Theodosius, Goettling, p. 61; *κρουστικοτέρα γιγνομένη ἡ λέξις ὀξύνεται*, Schol. Dionys. Thrax. Bekker, ii. p. 690.

With regard to the modern Greek dialect generally, I would observe that though the place of the accent has been changed in a few classes of words, in the great majority of cases it has been retained; and that in the case of curtailed words, as μάς for ἐμᾶς, πίσω for ὀπίσω, ψάρι for ὀψάριον, παιδί for παιδίον, δὲν for οὐδὲν, &c., it is the stress upon the medial accented syllable which has secured its permanence after the initial or final unaccented syllable had dropped off.

But the most incontestable proof that accent means emphasis lies in the doctrine of ENCLITICS; for in Greek as in English there are certain little words, such as the *pronouns* or the negative *no,* which in common cases are purposely kept unemphatic, and pronounced so rapidly as to appear to lean upon (ἐγκλίνω), or be taken up by the previous or following word; but the moment that the necessity of speech demands these words to become prominent, they receive the accent, and become emphatic. Thus we say, "*give me the book,*" like *datemi* in Italian, as one word, but "*give* MÉ *the book,*" that is, give it to *me,* not to *you.* Now, there could not be a stronger fact than this to prove that Greek accent meant emphasis; for this use of the acute accent to emphasize in particular cases otherwise unemphatic words is quite common, as, for example, in the case of the negative particle μὰ Δία οὐκ ἔγωγε, contrasted with οὕτως λέγεις ἢ οὔ, do you say so, or do you *not?*

6. Lastly, the analogy of the modern Italian compared with the ancient Roman, plainly shows us both the obstinacy of accent as a fact in the life of language, and what accent really meant in ancient Rome and Greece, as in modern Rome. For nothing is more certain than that, though its special laws were different in the two learned languages, accent, as an accident of articulate speech, did not mean one thing in Greece and another thing in Rome; but the Greek and Latin accent were in their nature and operation identical; so that what is predicated of the essence of the one must be considered as predicated of the essence of the other. If, therefore, the modern Italian accent, in its position and power so evidently identical with the old Latin, possesses the element of stress as a prominent feature, it is a legitimate conclusion that the Greek accent did so too. Altogether, it may be remarked as a very extraordinary fact, and indicative of the operation of some strange deluding prejudice, that, while the most formidable artillery of erudite arguments have been brought to bear against pronouncing Greek with Greek accents, no learned Latinist has yet written a book to prove that Latin ought not to be pronounced with Latin accents. When reading Latin we put the stress on the accented syllable exactly where CICERO, and QUINCTILIAN, and PRISCIAN say it was placed; but the moment a Hellenist gives the natural predominance to the accents which he finds marked on his books, he is immediately told that accent does not mean stress, but means something that no man can understand or make use of. Whence this inconsistency?

Having thus proved, by what may surely seem sufficiently strong arguments, that accents mean nothing in Greek, which they do not equally mean in English, or Latin, or Italian, there remains only to take a bird's-eye view of the somewhat remarkable literature of this subject, from the revival of letters down to the present hour. Such a review will at once be the best justification of the principles above set forth, and will place vividly before the reader the partial and inadequate points of view from which the opposing doctrines have taken their rise.

Now, in tracing the stream of confusion which this matter exhibits to its fountain head, it is most natural that we should, in the first place, turn to ERASMUS, both because he was the most prominent scholar of European reputation in the eventful age to which he belonged, and because it is quite certain that before his time no learned man ever dreamt or could have dreamt of disowning the pronunciation of the Greek language, which Europe had received as a common legacy from the Constantinopolitan Greeks. The early scholars, indeed, were occupied with matters of far more serious import than the exact accentuation and quantification of syllables. They read the Greek books for the information they contained: HERODOTUS for history, STRABO for geography, THUCYDIDES for political wisdom, PLATO for philosophy, ARISTOTLE for science. So long as this appetite for the stores of Hellenic thought and knowledge was the one thing needful, no man had either leisure or desire to put curious questions to himself with regard to the auricular luxury of a just orthoepy. But the time must come when this matter also would be examined: HOMER and SOPHOCLES could not be read in their mother tongue by men who used their ears as well as their eyes, without provoking questions as to the best method of bringing out the full music of that most musical of human languages which it was the happy fortune of these great poets to employ. If Greek was the language of the gods, there seemed a manifest impiety in allowing it to be enunciated by a confused, degraded, and irrational elocution. And, if such questions were to be raised, ERASMUS was precisely the man, who, from his fine genius, cultivated taste, and broad human sympathies, was best fitted to raise them. Accordingly, in the famous dialogue, "*De recta Latini, Græcique sermonis pronuntiatione,*" published at Basle in the year 1528, the whole subject is brought under review; and the text of his discourse is in the broadest terms, that "*nunc tota fere pronuntiatio depravata est tam apud Græcos, quam apud Latinos;*" and this is proved in a very exhaustive style in an argument extending to above two hundred pages. The powers of the different letters are critically discussed, and the relation of accent and quantity illustrated both by learned rules and by living examples. With regard to the vowel sounds, which is the first point handled, he had an easy task to prove that the slender sound the characteristic of the Byzantine Greeks could not have been the original sound of so

many distinct vowels and diphthongs. Signs of different vowels were certainly not made originally to confound, but to distinguish. The confusion in this case is always of a later birth. What ERASMUS, however, failed in here, and what, from want of materials, he could not but fail in, was to show at what period this confusion commenced; for, as the most polished nations in modern times display in their speech abnormal tendencies and depravations of all kinds, which are consecrated by usage and fashion, so there is no reason why the itacism of the theologians of Byzantium should not have been practised by the philosophers of Alexandria, and even, to a certain extent, by the orators of the Periclean and Demosthenic age. However, this was not curiously looked into; and the result was that, by this assault of ERASMUS, the faith of scholars in the orthoepic traditions of the Byzantine elders was shaken in all the most learned countries of Europe, and every nation set up vocalizing Greek according to what seemed good in its own eyes. Hence the motley babblement of Greek which now prevails. The old foundations were removed before the ground was opened, or the materials ready, to make new ones. And thus it has happened that an orthoepic reform, well intended, and in so far conducted on rational principles, has issued in an extremely irrational and altogether unsatisfactory result. So much for Greek vocalisation. With regard to that other matter with which we are specially concerned here, we do not find, what we might perhaps have expected to find, that the great modern innovation of disowning Greek accents in reading Greek, receives the slightest countenance from ERASMUS. On the contrary, part of the bad pronunciation which it was his object to reform was precisely the ignorance or loose observance of the proper accents in Greek and Latin, according to the characteristic laws of each language. He saw also everywhere amongst careless, tasteless, or ignorant speakers, that confusion of things so distinct as accent and quantity, which from the same causes prevails so largely at the present day. Scholars still tell you that accent and quantity annihilate each other, and cannot both be observed, meaning only, in fact, that for their particular ill-tutored and perverted auricular organs, it has become difficult, and is perhaps impossible. It certainly is impossible for a sharp, hard Aberdonian to speak with the rich silvery mellowness of a high-bred English lady; but the difficulty lies in bad habit, not in Scottish nature. On the superinduced habitude which erudite ears have so often displayed in not being able to distinguish accent from quantity, there is a passage in the Erasmian tractate, which we shall be excused for inserting at length:—

"*Sunt quidam adeo crassi, ut non distinguant accentum à quantitate, quum sit longe diversa ratio. Aliud est enim acutum, aliud diu tinnire: sicut aliud intendi, aliud extendi: quanquam nihil vetat eandem syllabam et acutum habere tonum, et productum tempus, velut in* vĭdi, *et* legi *præteritis. At eruditos novi, qui, quum pronunciarent illud* ἀνέχον καὶ ἀπέχον, *mediam syllabam, quoniam tonum habet*

acutum, quantum possent producerent, quum sit natura brevis, vel brevissima potius. Et ferè qui Græca legunt, accentus observatione confundunt spatium moræ, sic enunciantes μενέλαος, *quasi penultima sit brevis, et* μενέδημος *quasi duæ postremæ sint breves, quemadmodum in* θεόδωρος παράκλητος, εἴδωλα, *aliisque innumeris. Nec ita multis contingit sonare Græca, ut accentuum simul et morarum rationem observent, vel in carmine. Loquor autem non jam de vulgo, sed de eruditissimis quoque. Minus est erroris in Latinis, sed tamen illic quoque tonus acutus ac inflexus obscurat cæterarum sonum, ut in* videbimus, *congruit accentus cum quantitate, at in* legebâmus, *sola penultima videtur esse producta, quum secunda sit æque longa: in* amavérimus *sola antepenultima, quum ea sit brevis, secunda producta. LE. Omnino sic obtinuit usus, quem dediscere difficillimum est. UR. Atqui qui degustarunt musicam, nullo negotio distinguunt inter longam, brevem, et inter acutam et gravem. Nihil enim est aliud pronunciatio, quàm modulatio quædam vocum numerosa. Est enim et in oratione soluta pedum ratio, licet non perinde certis astricta legibus ut in carmine: quæ si confundatur, non magis erit oratio quàm cantio in qua graves cum acutis, longæ cum brevibus temere confunduntur. Unde quidam priscorum grammaticorum non inscite dixerunt, accentum esse animam dictionis. Et tamen hodie talis est etiam eruditorum pronunciatio, qualis esset illa ridicula cantio. Scis opinor canere cithara. LE. Utcunque. UR. Nónne frequenter imam chordam pulsans producis sonos, et summam tangens brevibus insonas aut contra? LE. Frequenter, quanquam hoc discrimen evidentius est in flatili musica. UR. Unde igitur nos sumus usque adeo* ἄμουσοι, *ut omnes acutas syllabas sonemus productiore mora, graves omnes corripiamus? Vel ab asinis licebat hoc discrimen discere, qui rudentes corripiunt acutam vocem, imam producunt. LE. Idem propemodum facit cuculus.*"

The only other interesting point, with regard to the present matter, which requires to be mentioned here, is that Erasmus distinctly teaches that *verses, both in Greek and Latin, are to be read with an accurate observance both of accent and quantity.* The difficulty and alleged impossibility of doing this, so much spoken of by modern scholars, he supposes to arise only from the gross neglect of the art of elegant reading in modern education. How far he is right in applying the spoken accent thus sweepingly to the rhythmical recitation of poetry, we shall have occasion to consider afterwards.

But what to the fine genius and well-trained ear of Erasmus presented no difficulty, to the gross majority who take everything without discrimination in broad masses was so formidable, that they do not even seem to have had the courage to look the difficulty in the face, but quietly settled down into a habit of confounding accent and quantity, and making all accented syllables long. This is distinctly mentioned by the next champion in the field, Adolph von Meetkerche (vulgarly Mekirch), a Flemish nobleman, born at Bruges in the very year when Erasmus' book was published, and well known in high circles

in England, from his having lived and died at London as an attaché of the Belgian ambassador at the court of ELIZABETH. He was, besides an able diplomatist, an accomplished scholar, and in the year 1576 published a Discourse "*de verâ et rectâ pronuntiatione linguæ Grecæ,*"* which seems to have given the first impulse to the paradoxical movement which caused the Greek accentuation, so laboriously preserved by the Alexandrian grammarians, to be thrown overboard in the general practice of scholars, and the vulgar Latin accentuation substituted in its place. The principal part of this work is occupied with the question which then loomed most large, whether the Byzantine vocalisation should be retained, or a reformed one introduced, as suggested by ERASMUS; but, in a short appendix, the doctrine of accents is stated succinctly, and, what is more important, the author's practice with regard to their observance. In the first place, he tells us the important fact that, in his day, Greek was so read by many, confounding accent and quantity, as altogether to destroy the perception of any poetical rhythm. "*Manifestus est eorum error qui tonos cum temporibus confundunt, ita ut quœcunque acuenda vel flectenda est syllaba, eam producant: quœcunque deprimenda vel œquabiliter pronuncianda, eam corripant. Ex quo fit ut in Grœcâ oratione vel nullum vel potius corruptum numerum intelligas, dum multæ breves producuntur, et contra plurimæ longæ corripuntur; ut pœne præstiterit Grœca vel Latina non legere quam ita fœdé depravare*" (p. 175). And no wonder; if, as he says, the accent was allowed such a power that, in the second line of the Iliad, ἔθηκεν was read as a dactyle, and the two final syllables of οὐλομένην as a spondee. And then he tells us of a general practice of schoolmasters, which by the way prevails in England almost universally to the present hour. "*Solent enim pœdagogi vulgo ita suos erudire ut in omnibus dissyllabis penultimam producant.*" Just as in Eton and Harrow the boys had, till very recently, if indeed they are not still, taught or carelessly allowed to say, *bōnus*, and not *bŏnus*. He then goes on to show how this practical assumption that a penultimate accent must necessarily lengthen the vowel has no foundation in the real nature of accent and quantity, of which the one expresses the quality of the sound, the other the dimensions. And then anticipating an objection often made in modern times, he goes on to say, "*Neque tamen nego brevi syllabæ temporis aliquid accedere, quando acuto signo signatur, quantum scilicet necesse est in acuendâ syllaba consumi; sed, ut minus sit brevis quam antea, minime tamen consequitur habendam esse pro longâ, sicut ab iis habetur qui* MĀLUS *arborem a* MĂLO *adjectivo non distinguunt*" (p. 178). This is exactly what ERASMUS had said; and one should think it would be sufficiently patent to all ears, except those of stupid schoolmasters, careless schoolboys, and bookish scholars, whose learning is all in their eyes, and not in their ears. But things easy in speculative thought become in the hasty practice of life, sometimes tolerably difficult; and, in fact, a just

* Reprinted in "HAVERCAMP's Sylloge." 1736. Vol. i. p. 9.

and true pronunciation, even in the case of the mother tongue, is not attainable without a certain amount of trouble. MEETKERCHE accordingly finds that his argument for accents, however just, is liable to be met with the objection which nullified so many of SOLON's well-conceived legislative reforms. The laws were no doubt very good, but they were too good for the people. The best for them was not the best absolutely, but the best which they could endure. "*At enim,*" he continues, "*dices, ista* (*i.e.*, the right pronunciation both of quantity and accent) *esse perdifficilia, et fortassis etiam ἀδύνατα, iis quidem qui diversæ pronuntiationi assueverunt. Id ego vero fateor, et in me ipso non invitus agnosco. Sed nihil vetat rectam viam aliis ostendere, etiam ut illam ingredi non possis. Certè veritas mihi dissimulanda non fuit, ut paullatim meliora probare et sequi condiscamus. Ergo, ut libere dicam quod sentio, vel tonos prorsus sublatos esse velim, tantis per dum depravata illa pronunciatio tonorum pro temporibus emendetur* (*quum præsentim veteres constet istos apices in scribendo non usurpasse*) *vel nullam eorum rationem haberi.*"* Which simply means that he is in favour of suspending the operation of Greek accents till such time as schoolmasters—proverbially not a very teachable race—shall have learned to distinguish *ŏs*, a *bone*, from *ōs*, a *mouth*, and that *căn'o* is a possible combination of articulate sounds, as much as *caw'no* or *caē'no*.

The next important work which falls to be noticed indicates plainly by its title—"*De Poematum cantu et viribus Rhythmi;*" Oxon. 1673—from what quarter the attacks of a section of the learned world were now to be directed against the traditional sway of Greek accents. The author of this tract was the celebrated ISAAC VOSSIUS, "unquestionably," to use the words of MARKLAND, "a very learned man, but whose whimsicalness and love of paradox scarce leaves room for him to be considered a reasonable one."† VOSSIUS, like MEETKERCHE, had got his ear possessed with a genuine living appreciation of the beauty of measures and rhythm in poetry, which justly resented the barbarism of those scholars who read ancient verse by accents, just as if it was so much German or English verse. In expressing his indignation strongly against these systematic murderers of the regal majesty of Latin, and the luxuriant swell of Greek verse, Voss did well; but, when he went farther, and not content with the interim act of suspension passed by MEETKERCHE, stood up in violent revolt against the whole accredited system of accentuation in the Greek language, and cast it, to save the ship, like a Jonah overboard, he committed a great mistake, and kicked vehemently against the pricks, where he could only wound his own legs. He declared roundly that the whole system of Greek accents, as we now have them, was a modern invention, or, at least, a corruption, or a monstrous compound of both;

* HAVERCAMP's Sylloge. Ludg. Bat., 1836. Vol. i. p. 179.

† Letter to FOSTER in the Essay on Accent and Quantity. 3d edit. London, 1820. P. 207.

that accents were originally musical marks, and had nothing to do with the pronunciation of the language; that the best proof of this was the unrhythmical jar which they produced, when actually applied to the recitation of verse, whether Greek or Latin; and that therefore the only course left to the scholar of taste was to disregard them altogether, and use only such accent as was manifestly dictated by the march of the metre. While, however, this ingenious scholar found it comparatively easy work to pronounce a dictatorial sentence of eternal exclusion against Greek accents, of which few had any real knowledge, he found himself obstinately met by an obvious objection from the familiar practice of the Latin tongue, which, while it distinctly disowns (except in a very few exceptive cases) all oxytone accentuation, nevertheless, in verse, constantly uses an emphasis, which falls with marked effect on the last syllable of one or more words in the verse. In answering this objection, Voss fell upon an aspect of the case, which, if he had applied it to Greek poetry, might have saved him from the trouble of beating vainly against the strong bulwarks of Alexandrian and Roman and Byzantine tradition in the matter; for he distinctly says that singing is one thing and reading another, and that the Romans may have followed a different law of accentuation with regard to each. "*Quare non quidem multum refragabor, si quis in recitatione Latinorum poematum ultimas syllabas unquam productas fuisse negaverit: sed vero in* CANTU *id ipsum fieri potuisse si quis contendat, idem etiam merito affirmet et Latinos canere nescivisse.*"*

Close upon the traces of VOSSIUS comes a German, HENRY CHRISTIAN HENNIN, whose work entitled "Ἑλληνισμὸς ὀρθῳδος, Traject ad Rhenum, 1684," with a great flourish of trumpets on its title-page, proclaims itself to prove "*Græcam linguam secundum accentus, ut vulgo ab omnibus hucusque fieri consuerit, pronunciandam non esse.*" The inspiration of this book—for it is full of fervour and emphasis, and a sort of lofty protestation—manifestly is the same as that of Voss' treatise; a certain school of scholars with whom the writer had been familiar, or it may be all the scholars of his time and place had got into a habit of sacrificing the rhythmical recitation of Greek poetry to the traditional accentuation of Greek prose, a usurpation, no doubt, of a most gross kind, and which it was obvious to think could best be got rid of by not only dethroning the usurper and telling him to keep to his proper place, but by killing him outright, and casting him down among the dead men with a triple volley of curse and execration. It was a procedure akin to that in political history, when democracy dethrones despotism, and acts ten times more despotically than the tyrant whom it overthrew. In conducting his indictment against the accents, the author commits in the outset the very transparent blunder of confounding the marks of the accents in printed books, with the living accents in the mouth of the people who spoke the Greek language. These marks, whether present or absent in books,

* Deviribus rhythmi, p. 44. *N.B.*—By *productas* in this passage he evidently means *accented.*

do not in the slightest degree affect the question; they do not exist in English books, and yet English words have a well-known accent in the voice of the English people, and as made visible artificially to the eye in the pronouncing dictionaries of WALKER and other orthoepists. The next great error made by HENNIN lies in the theory—for it is a mere baseless theory—that the accents were invented by ARISTOPHANES of Byzantium, for some purpose quite different for that which they now subserve. This is simply to leap over the testimonies of the most learned Greek grammarians from the time of the Alexandrian scholars to the taking of Constantinople by the Turks. And in order to make such a hypothesis possible and even plausible, he draws a flaming picture of the barbarism which corrupted the Greek language at a fever pace from the Roman to the Turkish conquest. All this, however, is purely imaginary, as any person who has looked even superficially into Byzantine literature must confess. Whatever changes in the course of time naturally might take place in the spoken language of the Greeks, the last element that would be touched by the change was the accentuation; and that not only from its own natural obstinacy, but from the very fact that the proper place of the accent visible in most written books presented a stereotyped norm, that checked all arbitrary deflexion in the start. Any other arguments that make a parade in HENNIN'S book are based on the fact of which we hear so much in these days, that certain persons could not pronounce ἄνθρωπος without saying ἄνθροπος, and certain other persons imagined that it was impossible to do so. After overleaping heroically the bristling fence of historic testimony on the matter, the author proceeds to lay down four rules of accentuation, which, both in the Greek and Latin languages are, "*sine allâ exceptione æternæ veritatis.*" These rules are as follows :—

(I.) "*Omnis vox monosyllaba modulationem habet in suâ vocali ut* Θῶς, *νοῦς, mons, pons.*"

(II.) *Omnis vox dissyllaba modulationem habet in syllabâ priori, ut* λόγοι, ὅδοι, *φώνη.*"

III. "*Omnis vox polysyllaba penultimam longam modulatur ut* ἀνθρῶπος *τυπτῶμεν, Græcorum, jucúnda, Romanorum.*"

IV. "*Omnis vox polysyllaba, penultima brevi, modulatur antepenultimam ut dóminas,* ἄλογον."

This is certainly one of the most cool pieces of insolent one-sided dogmatism that the history of learning presents, the whole affair being simply an assertion that the particular method of accentuation in the Latin language, which the author had inherited from secular and ecclesiastical Rome, should be stilted up into an eternal norm of accentuation for all languages, while the most plain and obvious facts, both in ancient Greek and modern English, which contradict the theory are held as non-existent, and excluded from the calculation; an instructive

example of the truth of GOETHE's remark, that truth is often disagreeable to us, because it limits the despotic sweep of our one idea, while error is grateful for this, above all other reasons, because it prostrates fact and thought and history before the triumphant march of our infallible conceit.

It was not to be supposed that the sweeping dictatorial dogmatism of this book of HENNIN, backed as it substantially was by the high authority of VOSS, would pass without comment from the learned of the Continent; and accordingly we find that in the year 1686 it received a long and able reply from JOHN RUDOLPH WETSTEIN, professor of Greek in the university of Basle. WETSTEIN's book, by an overwhelming array of historical testimony, enforced by sound argument, demonstrates the utter untenableness of the proposition of his adversary, unwarrantable equally in the wholesale swamping of the Greek by the Latin accent, and in the elevation of this latter into a rational norm of accentuation, by which the excellence of all articulate speech is to be measured. With regard to the main difficulty which had staggered MEETKERCHE, the Basle professor quietly reminds his antagonist, in the words of QUINCTILIAN, that the recitation of verse is in many respects different from the speaking of prose, "*imprimis lectio virilis et cum suavitate quâdam gravis, et non quidem prosæ similis, quia carmen est.*"

The infection of this notable dispute now comes to England, and the first oracle to whom we feel inclined to propound the question for solution is, of course, the great BENTLEY. This massive and masculine scholar, in the short treatise on metres prefixed to his edition of "TERENCE," has the following passage:—"*Tam vero id Latinis comicis, qui fabulas suas populo placere cuperent magnopere cavendum erat ne contra linguæ genium ictus seu accentus in quoque versu syllabas verborum ultimas occuparent. Id in omni metro, quoad licuit, observabatur; ut in his*

'Ar'ma virúmque cáno, Trójae qui prímus ab óris,
Itáliam fáto prófugus, Lavínia vénit
Lítora; multum ílle et térris jactátus et álto
Vi súperum, saévae mémorem Junónis ob íram.'

Qui perite et modulatae hos versus leget sic eos, ut hic accentus notantur, pronuntiabit, non ut pueri in scholis, ad singulorum pedum initia;

Italiám fató profugús, Lavinaque venit, *sed ad rhythmum totius versus.*"

Now, it in no wise concerns us to discuss the value of the remark here made as to the practice of the Latin poets; that is a delicate matter, we believe, not so easily settled as the stout Cantab seems to have imagined. The only significance of the passage for our present inquiry is, that the writer believed that in some way or other the structure of Latin verse was regulated by a regard to the spoken accent, and not simply by the law of quantity and the metrical beat.

What truth there may be in this notion will appear in the sequel; meanwhile it is quite plain that it leaves the matter in a state of considerable uncertainty, an uncertainty which is not at all diminished by the unquestionably rash assertion in the letter to MILL, that Greek accents were an invention of later times, which could only mislead the accurate scholar.* An *obiter dictum* of this kind, even from a BENTLEY, on a confessedly difficult question, cannot be regarded as having any real weight. It may, however, along with other causes, have contributed to produce that strange aversion to Greek accentuation so characteristic of English scholarship.

We now advance by a long stride into the middle of the great battle of accent and quantity that was fought in this country about the middle of the last century. The protagonist of this warfare is the Rev. HENRY GALLY, a Kentish Doctor of Divinity, and chaplain to His Majesty King GEORGE II. His dissertation against Greek accents was first published in the year 1754, seventy years after the famous works of HENNINIUS and WETSTEIN; and quite recently on the back of two treatises on the same subject, which had appeared in Rome.† Dr GALLY wrote, quite aware of the achievements of his predecessors, but convinced that their attempts to untie the Gordian knot were unsatisfactory, and that his own method was altogether new and original; and so it is, no doubt, in some things, but novel only in the daringness of its assertions and the glaringness of its absurdity. Its absurdity consists mainly in the writer's belief that he can overturn the whole principles and practice of the Greek accentuation, by simply saying that it is irrational and absurd, as if some famous philosopher, some thousand years after this, when the English orthoepy may have become a field for learned debate, were to say that *Mac'Intosh* and *Mac'Intyre* could not have been pronounced with the accent on the first syllable, because it is irrational to place the accent on the common element of the *Mac*, instead of on the distinguishing element, the clan; which rational method of pronunciation, as above remarked, exists not only in all the other Macs, but in all the Saxon names ending in *son*, as An'derson, Péterson, not *Anderson'*, *Petersón*. A writer belonging to a people whose pronunciation is in all points so various, so arbitrary, and so dependent on fashionable caprice as the English, might surely have spared himself the inconsistency of such an argument. In the other parts of this learned divine's book we find merely a repetition of what had been said by MEETKERCHE, HENNINIUS, VOSSIUS, and others. Accents, we are told, were entirely musical, and had nothing to do with the intonation of colloquial speech: then it is broadly asserted that accent necessarily constitutes quantity,

* "Notæ accentuum quorum omnis hodierna ratio præpostera est atque perversa." Works by DYCE, vol. ii. p. 362,

† (1) Sarpedonii dissertatio de vera Atticorum pronunciatione. Romae, 1750. (2) Velaste dissertatio de literarum Græcarum pronunciatione. Romae, 1751.

and therefore *must* be wrong; and that, whatever the advocates of accents might preach in theory, in practice they never did, because they never could observe the accents without destroying the quantity. This practical difficulty is, in fact, the gist of his whole treatise, as is manifest from the very notable words with which he concludes:—"If, therefore, we would observe uniformity, and keep to what we can safely rely on, we must not admit of any use of accents in the pronunciation of the ancient Greek language but what is consistent with quantity; and if we have lost the nicer part of the ancient pronunciation, we have the more reason to adhere to the essential part which still subsisteth." And this way of putting the case, viewed as an *argumentum ad hominem* addressed to the great mass of the English scholars and teachers, is no doubt perfectly just; for these gentlemen had got into a monstrous and irrational habit of writing Latin and Greek verses with much labour and wonderful dexterity, by help of their understanding only, against the verdict of their ears, and treated both accent and quantity as an affair of dead rules, not of living vital action.*

But English scholarship—whatever might be the absurdities of professional pedagogy—was not destined to surrender one of the strongholds of venerable philological tradition at the trumpet-blast of such a windy dogmatist as Dr Gally. In the year 1767, a reply to his pretentious heresy was sent forth from Eton, by Foster, in which, so far as the learning of the subject is concerned, he showed himself as superior to Gally as Wetstein was to Henninius. He proved, beyond all possibility of denial, that accent had always been a recognised element in Greek orthoepy, and was in no sense the barbarous creation of a decadent age and a degraded taste. He stated also most distinctly that, while elevation of tone was the most characteristic element in Greek accent, it also necessarily included the element of *stress*—which Dr Gally also saw clearly—but that this stress or emphasis was in no case to be confounded with the length or duration of syllables. Hence, indeed, the great superiority of his argument to that of the Kentish D.D.; for he not only maintained that accent was not to be confounded with quantity, but that, from the very nature of the case, the intense energy of the acute accent might, in many cases, have a tendency to shorten rather than to prolong the emission of breath by which it was enunciated.† With regard to the main difficulty, however—the practice of the theory, which, as we have seen, was the stumblingblock of Dr Gally—he does not seem to advance the matter far. Hear his words:—

"Nor let it be said, if we should retain these sounds, we can never apply

* On this notable inconsistency of those champions of quantity who denounce accent, Mr Foster is justly severe; ch. x., on accent-quantity.

† On this point he produces a remarkable passage from Suidas, *in voce* ὀξύ, vol. ii. p. 1136. Bernhardy.

them to their proper use in practice. Who can affirm that with certainty? An English voice was capable of doing this in the time of Henry VIII., and why not now? Sir JOHN CHEKE declares it not only practicable, but that it was actually practised, and that he knew many persons who could express these sounds consistently with accent and quantity perfectly well. I know one person who, after a few trials, is now able to do the same." By this one person, the reader will naturally suppose that he means himself, though it is a pity he did not say so in a manner that could not admit of ambiguity. But whoever the individual might be who in the year of grace 1761 had solved this easy vocal problem, curiously imagined to be so difficult, schoolmasters who sinned against this high ideal of classical recitation might well reply, that to attempt to indoctrinate the ears of schoolboys with such delicate distinctions would prove as hopeless as to bring out the beautiful harmony of one of HÄNDEL'S operas from a hurdy-gurdy. On another point also, FOSTER'S Essay, though victorious against GALLY, did perhaps more harm than good to the question of orthoepic reform in the great schools. He does not always sufficiently distinguish between the emphasis, or stress, or intensity of utterance, which he rightly considers to belong essentially to accent, and the prolongation of sound with which that intensity may sometimes be accompanied. Hence he speaks of the effect of the accent in English being habitually to lengthen the syllable; whereas, if we attend to our ears, words like *văp'id* and *răp'id*, are just as common in our language as *po'tent* and *pa'tent*, and no person feels himself under any tendency or compulsion to assimilate the pronunciation of the first two words to that of the other pair.

Three years after the appearance of Mr FOSTER'S Essay, the "*Accentus Redivivus*" of PRIMATT appeared, the title of which seems sufficiently to indicate that in England at least MEETKERCHE, and VOSS, and GALLY, had practically won the day, and that accents had retired from the schools, and even from the typographic theatre in Oxford; for in the year 1759 an edition of ARISTOTLE'S Rhetoric, without accentual marks, had appeared under the imprimatur of THOMAS RANDOLPH, Vice-Chancellor of the University. How many more Greek books, in the same nude fashion, may have issued from the same quarter about the same time, I do not know; but there was certainly just cause for the champions of accents to take the alarm; and so Mr PRIMATT marched forth, an accentual cataphract, bristling all over with Alexandrian and Byzantine erudition, through which it was impossible to pierce him. In his learned work, he first shakes himself free from the notion flung out by VOSSIUS, and the extreme men of the rhythmical party, that accents, however they might have been observed afterwards, were originally a musical, and not an orthoepic notation. He then shows, by a long historical deduction, that the reading of Greek prose always was accentual, and that nothing can be more illegitimate than to

transfer to prose the laws of quantitative rhythm, which belong to poetry. But in this second proposition unfortunately, he is only half right, and entangles himself and the whole subject in a network of the most hopeless confusion; for, in defining accent, besides asserting with FOSTER, that there is an overbearing tendency in English to lengthen all accented syllables, and an invariable rule in Latin to accentuate long penults, he lays it down in the strongest terms that the acute accent necessarily lengthens the syllable on which it falls, and that, in fact, when properly read, every accented syllable in Greek prose is long. Nay, more, so confused are his ideas on the whole terminology of the subject which he treats, that he actually tells us "we can hardly read a verse in VIRGIL or HOMER in which the *rhythm* does not more than once break in upon the *quantity*" (p. 157), a sentence which, according to the usage of all who write intelligibly on such subjects, is pure nonsense, or true only of such accented verse as we have in English and other modern languages. This extraordinary confusion of two things by the ancient grammarians, kept so distinct as accent and quantity, rendered his whole discourse nugatory. To accept accent according to this theory was to make a formal transference of quantity from one syllable to another, and to acquire a habit of reading prose, which, in the point of quantity, would require to be reversed the moment a scholar threw down PLATO, and took up SOPHOCLES. In a country where the most elegant scholars, under the guidance of such a Titan as BENTLEY, had already begun to look with a curious preference on everything connected with metrical composition, such a startling doctrine could not be expected to make converts.

After these violent but practically ineffective efforts, the great strife about accents in England stopped for thirty years, when in the year 1796 another remarkable combatant entered the lists in the person of SAMUEL HORSLEY, one of the most notable of the singular army of erudite polemical bishops of which the Anglican Church has been so fertile.* Into the weakness and utter untenableness of the received method of reading Greek in this country the Bishop casts a piercing eye, and with an outspoken emphasis calls black black, and white white in the matter, after a fashion to which it might have been expected that in a country where the Church has so much to say in the school, some serious attention might have been given. "*A practice*," he says, "*is adopted in this country of reading Greek verse with the Latin accent, and this is most absurdly called reading by quantity; and having adopted this strange practice of reading one language by the rules of another, it is not unnatural that we should wish to prove the practice right*" (pp. 26, 27). This is indeed hitting the nail on the head; but the strange practice, like many strange things in England, still

* On the Prosodies of the Greek and Latin Languages. Lond. 1796. The author's name was not given on the title page.

continues, and we still make ourselves ridiculous by awkward endeavours to prove that what is altogether unnatural and monstrous is justifiable and even beautiful. How is this? Not only, I believe, because the patient was self-willed and obstinate, but because the physician who pronounced a most scientific diagnosis of the disease had not the sagacity to discover the proper cure. He suggested a cure more flattering to his own ingenuity than true to the state of the case, or beneficial to the patient. He was as original as Dr GALLY, in a more subtle indeed, but not in a more practical way. GALLY's originality, as we have seen, consisted simply in calling everything on the doctrine of Greek accents irrational and absurd which was contrary to his orthoepic habits or fancies, and nonsuiting it, without more ado, as a defaulter *in foro rationis*. HORSLEY, with that respect for historical fact and erudite testimony which became a bishop and a theologian, admitted the doctrine of accent in its full weight, as an element of which no sane reasoner on the matter of Hellenic orthoepy could get rid; but, in order to explain its operation as part of the harmony of Greek verse, he invented a theory altogether novel and altogether arbitrary, which nobody had ever proposed before, and which nobody, we may feel pretty certain, will ever propose again. This theory consists simply in acknowledging the Greek accents, as we find them in the books, as the law for the pronunciation of the separate words, but refusing to allow them their natural force under certain rhythmical conditions. Thus, he says, that at the end of a hexameter verse such a word as ἔθηκε must be pronounced ἐθήκε, because the last syllable of a hexameter verse being long, the accent, according to a well-known canon of Greek orthoepy, must fall on the penult! Now, the objection to this theory is threefold—(1.) It is not true that the last syllable of hexameter verse, as ἔθηκε, is long; it is short, and the time is filled up by the pause which belongs to the end of the line, like a rest in music; (2.) The theory proceeds on a supposed connection between prose accent and rhythmical emphasis, which is fundamentally false; and (3.) The whole theory is a figment spun out of the brain of the writer, without a shadow of authority from ancient grammarians and metricians. This being so, the natural consequence followed;—the book explained nothing, and changed nothing. If everybody could not answer it, nobody cared to understand it.

Immediately upon the back of the learned Bishop's treatise, in 1797, appeared a little book entitled "*Metron Ariston; or, a new Pleasure Recommended,*" with a ruffed and bearded effigy of MEETKERCHE fronting the title-page, and a motto which sufficiently indicates the temper and direction of the writer—

> "*Tollite barbarum*
> *Morem perpetuum, dulcia barbare*
> *Laedentem metra, quæ Venus*
> *Quintâ parte sui nectaris imbuit.*"

This book was not written by a scholar, but by a man of taste and vivacity, and a gay self-reliance which stands him in good stead against a whole host of scholastic cuirassiers. In point of tendency and contents, this book is nothing more than a repetition of MEETKERCHE and VOSS, and those writers who have maintained the right of rhythmical as opposed to the accentual recitation of Greek and Latin verse; but the striking fact which the title of the book suggests is, that the masters and teachers of the great English schools, who certainly could not be accused of paying any partial attention to accent, were the very persons who had so thoroughly ignored the practice of rhythm in their teaching, that it was a discovery to the author of the book to find that there was such a thing as rhythmical reading of classic verse; and this discovery, with a prompt philanthropy, he hastens to communicate to the ingenuous youth of the nation under the inviting name of "a new pleasure." This entirely agrees with the complaint which we have just heard the right reverend Bishop make with regard to the absurdity of reading Greek poetry with Latin accents and calling it reading by quantity. No wonder that clever schoolboys on occasions should begin to dream that the learned and reverend doctors, by whom their ears had been indoctrinated in the unpleasant mysteries of long and short syllables, at bottom knew less about the matter than they might have known themselves with the help of a little unsophisticated juvenile instinct. And accordingly the writer of "Metron Ariston" tells us that "he always indeed had an idea that our very anomalous and irrational way of reading Greek and Latin poetry was founded on error; yet, from indolence, he had conformed, though reluctantly, to the general practice, because it was not his business to examine the error and seek its remedy." But what he did not seek for, he goes on to tell us, like WORCESTER'S rebellion, came in his way, and he found it; and the good HERMES, on whom he stumbled to direct him in his rhythmical wanderings one day, was a learned Italian ecclesiastic, while they were walking together in the *Campo Vaccino* at Rome one morning, and talking of HORACE, and quoting the well-known line—

"*Ibam forte viâ sacra sicut meus est mos.*"

The full musical weight with which the learned Italian recited this verse struck the Englishman with a pleasant surprise; whereupon the priest, divining the cause of his satisfaction, began to expound to him the correct theory of classical recitation according to MEETKERCHE, "the great ambassador of a little state." Against this true doctrine, without which verse had no meaning, and lost more than half of its suavity, the English scholars and schoolmasters were in the systematic habit of sinning, by pronouncing *ĕq'uus*, for instance, a *horse*, as if it were *aequus, equitable*—by shortening the final syllables of all words, and pronouncing *dŏm'inōs* as if it were *dóminŏs* and *sacrā*, the ablative singular, like

sacrâ the nominative plural; and by turning anapests into dactyles, dactyles into tribrachs, spondees into trochees, iambi into pyrrhics—in fact, doing everything that could be done systematically to turn order into disorder in this region, and "by this most abominably absurd custom, destroying at once both sound and sense, and seeming to sin from a love of the very ugliness of sinning." These are hard words, but not, in fact, one whit more strong than those which we have quoted from the English Bishop; nor is it possible, indeed, to conceive anything at once more unscientific, more tasteless, and more unpractical than the way in which prosody and rhythm have been handled in the great English classical schools up to the present hour. On this point, certainly, the author of "Metron Ariston," a single light horseman, could triumphantly ride up and attack without fear a whole army of big blundering and self-contradictory hoplites. As to accents, however, about them he wisely said nothing; but allowed them quietly to lie in the state of suspended animation to which they had been condemned by his patron-god MEETKERCHE. If these mute, mysterious, little oblique and curved lines were ever to revive into speaking significance at the touch of some philological wizard, the author of "Metron Ariston" certainly did not possess the secret for their disenchantment; nor, indeed, if he had possessed it, would he have cared to use it; for the accents, whatever virtue they might possess, could add but little to the luxury of the new rhythmical pleasure which he had discovered.

But what were the great German scholars doing all this while,—the HEYNES, the WOLFS, and the HERMANNS, the founders of that stable and splendid edifice of philological learning which has placed Germany in the van of erudite and thoughtful research during the whole of the present century? In the preface to the second edition of his Odyssey, WOLF remarks that in the matter of the accents, "the editors of the previous centuries had shown a great laxness of procedure, a fault which had commenced with so illustrious a name as HENRY STEPHANUS, who in this respect had declined from the accuracy of his predecessors, CHALCONDYLUS and ALDUS." And after a few remarks on points of detail, follows a remarkable witness to the practical disuse into which accents had fallen in Germany just as in England towards the end of the last century. "In fact, no person now-a-days—and for many centuries back—ever *hears* a Greek accent; and only a few, indeed, seem to believe that the doctrine of the grammarians on this subject is a thing that belongs to a complete course of teaching."* This passage is decided as to the general disuse of accents among the Germans in WOLF's time; but the phrase *seit vielen Jahrhunderten* is certainly too strong; for the works of MEETKERCHE, VOSSIUS, and HENNINIUS, are sufficient to prove the living predominance of the Byzantine tradition in respect to

* These extracts are taken from an historical review of the opinions of scholars about accents in WAGNER's "Accent Lehre." Helmstadt, 1807.

accents in the scholastic practice of their time. An equally emphatic declaration in favour of accents is made by HERMANN in his famous work "*De emendandâ ratione Grammatices Græcæ;**" but whether these two illustrious scholars contented themselves with publishing an authoritative manifesto on the necessity of maintaining accents as an inherited doctrine of genuine Hellenic orthodoxy, or took any steps to put their views into that practical shape which alone could give them significance to articulate-speaking mortals, I have not been able to learn. Certain it is, however, that the stagnant waters of the schools—in Germany much more apt than in England to deduce practice from principle—began to be moved in this matter; and, according to information which I have from continental scholars of high reputation, the accents are now pronounced in a great number of the best German gymnasia. I myself, some forty years ago, heard Professor BOECKH, in Berlin, reading the Iambic verse of the tragedians with a distinct and well-marked observance both of accent and quantity. The matter appears to have been left pretty much to the arbitration of the scholastic world; and we may feel perfectly convinced that the natural conservatism of teachers would have resisted all change in this matter, unless it had been incontestably proved that the change carried with it the double advantage of scientific truth and practical convenience. Whilst the matter was thus not only fairly ventilated, but to a large extent embodied in the scholastic practice of Germany, in England not a single step seems to have been taken either to the recognition of the principle or the settlement of the practice of Greek accents. The well-known declaration of PORSON, no doubt, in a note to the Medea,† gave the imperial *imprimatur* to certain traditional marks as a fact on paper, and of course put a stop for ever to the inchoate practice of printing Greek books without such marks; but it was a fact which seemed to remain as mysterious as a row of hieroglyphics on an obelisk before the great decipherment of CHAMPOLLION. In fact, to use Scripture language, notwithstanding the authoritative dictum of the great Cantab, the doctrine has remained in England up to the present hour a meaningless thing, "having a name to live while it is dead." In Scotland, indeed, a country too much accustomed slavishly to follow English authority in classical matters, twenty years ago I published a short protest against the gross inconsistency and grave practical grievance of inculcating rules about a host of mysterious marks which gave neither ideas to the intellect nor direction to the ear;‡ it had become clear to me as sunlight, not only from meditation on the nature of the case, but from an accurate study of the ancient

* Ch. xiii. *De accentu.*

† "*Si quis igitur vestrum ad accuratam Græcarum litterarum scientiam aspirat, is probabilem sibi accentuum rationem quam maturrime comparet in propositoque perstet, scurrarum dicacitate et stultorum derisione immotus.*"

‡ The Pronunciation of Greek: Accent and Quantity; a Philological Inquiry. Edinburgh, 1852.

grammarians, that Greek accents contained the two elements of elevation and stress of voice, and are, in fact, practically identical with the accents in English, Italian, German, and other modern languages. And this truth I have carried out in practice for twenty years with increasing profit and satisfaction. In England, however, as was to have been expected, no attention was paid to a Greek argument coming from the north side of the Tweed; and, accordingly, in the next work, that of CHANDLER,* which issued from the Oxford press, we find the whole subject flung back into a grim limbo of despair, and involved in a mantle of impenetrable darkness. In the preface to his work, this author goes so far as to assert that neither PORSON nor any other scholar, "while sanctioning the practice of accentuating Greek by their example, has condescended to justify it by sound and conclusive reasons. PORSON specially, it is hinted in terms more vigorous than polite, "gave assertion for proof in the matter, actuated partly by his contempt for WAKEFIELD, who happened to entertain a different opinion from his own." Then he goes on to proclaim the utter hopelessness of being able to arrive at any certainty with regard to the meaning of accents; it is not even certain that they did not "indicate the length or shortness of syllables;" he denounces "the absurdity of those who perpetuate in writing a something to which they never attend in reading, and who persist in ornamenting their Greek with three small scratches, the very meaning of which is doubtful and perhaps unknown," and laments in the most pathetic terms his own evil destiny in having had anything to do with the tangled disorder of "these troublesome appendages."

> "*There's something wrong in accents—cursed spite*
> *That ever I was born to set it right!*"

In fact, it appears not a little extraordinary that a writer who uses such strong language, should not have followed out consistently the practice of his predecessor HENNINIUS, and flung the whole cargo of Byzantine lumber overboard; for what task can be imagined more irksome and more fruitless than to spend long months of painful inquiry, with fret of brain and vexation of vision, upon every mappik and dagesh of a gospel in which the writer does not believe? Almost contemporaneously with this remarkable book of Mr CHANDLER, appeared an interesting paper on accent and quantity by Professor MUNRO of Cambridge.† The occasion of this discourse was a Latin inscription in accentual hexameters from Cirta in Numidia, and supposed by the professor to belong to the third century of our era. In commenting on these verses, of course, the writer was led to explain both what accent meant, and how it came to pass

* A Practical Introduction to Greek Accentuation. By H. W. CHANDLER, M.A. Oxford, 1862.

† On a Metrical Latin Inscription, copied by Mr BLAKESLEY, at Cirta.—"Transactions of the Cambridge Philosophical Society," vol. x. part 2. 1861.

that accentual verse, at so very early a date, came to usurp the place of quantitative, which only we now acknowledge as classical. In making this explanation, Professor MUNRO lays down the following propositions :—

(1.) That the acute accent of the ancients was a mere elevation of the voice, without any stress on the accented syllable.

(2.) That in the composition of Greek and Latin verse, the metre was determined by quantity alone, and that accent had no influence on it direct or indirect.

(3.) That, nevertheless, the quantity of syllables was a matter which swineherds in the days of HOMER, and ploughmen in those of PLAUTUS, had imbibed with their mother's milk, and could discriminate with the nicest precision.

(4.) That by some strange and, to us, unaccountable process, the nature of the Greek and Roman accent was suddenly changed in such fashion that, from being a mere raising or sharpening of the tone, "it became a stress," "a mere stress," "a stiff and monotonous stress," a stress which is always accompanied with "the lengthening of the quantity," having nothing in common with the genuine classical accent except the name; and that by this strange and inexplicable plunge, the accentual poetry of the mediæval hymns, and the whole of our modern metrical system, so early as the third century had started into recognised existence.

So much for the theory of the matter. With regard to the strange and unscientific practice of the English great schools and colleges, the following passage is notable :—

"It appears from what has been said, that we English, in reading Latin, place the accent generally, but by no means always, on the proper syllable. But then, we have entirely changed its nature, making it a mere stress, instead of a simple raising of the tone, without any lengthening of the quantity. And PRÆCILIUS and his cotemporaries already did the same. From them, and their still more degraded descendants, the Italians, and other western nations, we inherit this debased accent, which had usurped and overthrown the rights of quantity. In the second line of the Æneid we read *Italiam fáto profugus* with the accent on the right syllable; but on the same principle we ought to say—and PRÆCILIUS, indeed, and the Romans for centuries after him, did say—*Lavináque*, with the accent on the second *a*. We flatter ourselves that we thus preserve the quantity, but that is a mere delusion. It we feel by a mere mental process. Whether we pronounce *prófugus* or *profúgus*, quantity is equally violated. In the same way we read Greek with this debased Latin accent, and fancy that we preserve the quantity while sacrificing the accent. The modern Greeks read old Greek with the ancient Greek accent, debased in the same way into a mere stress. We think them, they think us, in the wrong; and in different ways we are both equally in the wrong. Μῆνιν ἀείδε θέα in an English or

Italian, and μῆνιν ἄειδε θεά in a modern Greek mouth, are equally remote from the accent and quantity given to the words by HOMER or DEMOSTHENES."

It will be observed that this passage touches exactly on the same absurdity which, sixty years earlier, had roused the sprightly indignation of the author of "Metron Ariston," and the grave episcopal censure of Dr HORSLEY.

In the "Cambridge Journal of Philology," vol. i., for 1868, appeared an article on the English pronunciation of Greek, by W. G. CLARK, then public orator, Cambridge. Mr CLARK is a scholar particularly well entitled to speak on this subject, both from his general accomplishments, which are far from being confined to the ordinary routine of an English classical scholar, and specially from his having travelled in Greece, and taken note of the actual accents of the language, as at present spoken by the people. In theory, Mr CLARK entirely agrees with Professor MUNRO, that the ancient Greek accent consisted merely in the elevation of the tone, while the accent of the modern Greek includes "a stress precisely like our own, which is given by prolonging the sound, as well as by raising the note." When it falls upon a syllable it lengthens the vowel except before a double consonant. Thus λόγος is pronounced λώγος, ὄνος ὦνος, and so forth. With regard to scholastic practice, Mr CLARK is of opinion that, while our English Greek vocalisation is altogether anomalous and indefensible, and must be abandoned, the present system of reading Greek with Latin accents should not be touched, because the modern system of accentuation is widely different from the ancient, and its adoption could only tend "to confuse such ideas as we at present possess of the rhythm of ancient Greek verse." And again, "It is impossible in practice to recur to the ancient system of accentuation, supposing that we have ascertained it in theory. Here and there a person may be found with such an exquisite ear, and such plastic organs of speech, as to be able to reproduce the ancient distinction between the length and tone of syllables accented and unaccented, and many not so gifted may fancy that they reproduce it when they do nothing of the kind. For the mass of boys and men, pupils as well as teachers, the distinction is practically impossible." So Mr CLARK leaves us, so far as action is concerned, in a plight little better than that in which we were left by CHANDLER, —not enveloped, indeed, in impermeable mystery, but clogged with impracticable fetters, and groaning under a yoke of grammatical tradition which neither we nor our fathers were able to bear.

A strange and a grateful contrast to the general current of English scholarship on this subject is presented by Mr GELDART, of Balliol College, Oxford, in his interesting and ingenious book, entitled "The Modern Greek Language in its Relation to Ancient Greek; Oxford, 1870." In the third chapter of this work, the author states views with regard to accent and quantity which lift him completely out of what has always appeared to me the sort of enchanted

circle of confusion and delusion in which English scholars are involved the moment they approach this subject. Mr GELDART is a decided advocate for accents, both in theory and practice, and he says roundly that "our prejudice against accents is for the most part insular, and deepened, to boot, by the peculiarities of our own insular pronunciation." He blows to the wind in a single sentence the vulgar error of English scholars, so often noticed in these pages, that accent has the necessary effect of lengthening the syllable on which it falls, the accented syllable in English being, in fact, as often short as long, as in *gĕt'-ting, pĭck'-ing*, while a long syllable is often unaccented, as *fīnáncial, fértīle, a prīō'ri*, in which last the first syllable is nearly always pronounced long, in spite of the fact that it is short in Latin. It is accordingly a complete delusion to imagine "that the Latin accent is either an indispensable or an infallible device for marking the right quantity of Greek syllables." With regard to accent, he makes the just remark that the raising of the note, and the increase of the stress generally go together. He farther denies altogether—and on this point he is a witness of great authority—that the modern Greeks always, or even in a majority of cases, lengthen the syllable on which the accent falls; and in regard to the relation of accent and quantity, he shows that neither is modern poetry always governed by the mere spoken accent, nor is ancient poetry altogether regardless of it, but that the real regulator, both of ancient and of modern poetry, though in very different ways, is RHYTHM, which is determined by the musical beat. How far the spoken accent was heard, as it were, through the rhythmical movement, depended principally upon whether the verse was sung or recited. In pure singing there might be heard only a faint glimmer of the spoken accent; in prose it was the prominent element, and directed the flow of the period; while between these two extremes there might be several intermediate styles of utterance in which the spoken accent was more or less prominent, according to the greater or less approach of the style of recitation to colloquial prose.

It will not be difficult, after this long and strange historical survey, to sum up the conclusions to which, by the consideration of the various facts and arguments, we are inevitably led. We find ourselves, in fact, after more than three centuries of confusion, one-sidedness, and hallucination, arrived at a point of view where no fact or principle, necessary to a just conclusion, is concealed, and all apparent contradictions find a happy conciliation. In particular, the whole history of the controversy displays the fact that in one form or another quantity is the bugbear, and that from VOSS and MEETKERCHE, to MUNRO, CHANDLER, and CLARK, a sacred regard for the rights of metre is the apology for the monstrous invasion of the province of Greek by Roman accents. But those who have attended to the course of our argument and historic survey will

easily perceive that the interference of Greek accents with the laws of Greek metre is a pure hallucination; inasmuch as—

1. It has been amply proved that in the case of individual words the predominance given to one syllable by the stretch, stress, or emphasis of the voice with which the acute accent is naturally accompanied, has no necessary tendency to lengthen the syllable on which it is laid. Through the whole argument of those who oppose Greek accents a confusion runs between two things, which in this matter must be kept carefully apart—a confusion between a short syllable unaccented compared with the same syllable accented, and a short accented syllable with a long syllable accented. When the three terms ἥμε̆ρα, ἡμέ᾽ρα, and ἡμη᾽ρα are compared, the middle syllable of the middle term, while it is more prominent, and may be in some degree longer than the same syllable of the first term, is decidedly short when compared with the same syllable of the third term. If, therefore, any short syllable, whether in Greek or English, on which the accent falls, is in danger of being pronounced long, it arises not from the nature of the case, but from the ignorance, carelessness, or stupidity of the teacher; and, in fact, a great part of the strange confusion which has so long prevailed on this subject may not unreasonably be traced to the want of the directing presence of a living rhetorical and musical culture in our great English schools and colleges.

2. The second great element of confusion which has been introduced into this matter is the gratuitous and altogether unauthorised assumption, that because our metrical composition follows the laws of spoken accent, therefore in Greek and Latin the same law was necessarily observed. In the writings of Hyphaestion and of those who lay down the canons of classical verse, there is not a single word said about the spoken accents; and the sure inference is, that in metrical composition they were, as Professor Munro justly remarks, systematically ignored, or, if attended to at all, only in a subordinate, exceptional, incidental, and even accidental way. Nothing, therefore, could be more mistaken than the attempt of Horsley to give a new theory of Homeric scansion, founded on the doctrine of the spoken accents. On what principle, then, it will be asked, was the Greek poetry written? Can it be supposed that a nation of refined taste and high culture could be delighted with the barbarism of pronouncing words, one way in prose, and another way in verse? We answer, there is nothing at all strange in this supposition; and that, whether it appear strange or not, it was certainly the fact. To understand this, instead of transferring the laws of our modern poetry wholesale to the poetry of the Greeks, let us rather transfer ourselves from an age of books, reviews, newspapers. and reading-rooms into an age where there was no such thing as books or reading at all, where prose composition was altogether unknown, and where every composition, not purely ephemeral, was made to be sung, and had its existence

only in the element of music. Now, we need not at the present day set forth a formal proof that HOMER and the pre-HOMERIC teachers of Greece were not ἀναγῶσται but ἀοιδοὶ, and that all hexameter verse, the current form of the oldest Greek metrical compositions, was originally sung, and not recited. Under these conditions, it naturally conformed to the laws of musical composition; and what these laws were, especially in relation to spoken accent, it is not difficult to realise. What music principally demands from poetry is a mass of rich and full vocalisation, to correspond with the measured flow of the notes; for the vowels are the musical element in human speech, and especially the deep broad vowels pronounced long, and not rapidly rattled over. This element, therefore, was naturally preserved in the first place: that is to say, Hellenic poetry was founded on quantity. But what of accent? The rhythmical march of speech adapted to music, as every one knows, is secured by the element of equality expressed in the succession of equal spaces of sound, marked by recurrent emphasized pulsations; these pulsations constitute what is called the musical accent, or beating of time, as it is vulgarly called. Now, it certainly might have been desirable to make this rhythmical accent of the music correspond in every case with the spoken accent of the words; but this was not done, for the very simple reason that the choice of poetical language would have been too much fettered by the constant double demand on the poet of conformity in every case, both with the spoken quantity and the spoken accent. Nor should this appear at all strange. As it is, we see how often HOMER—as in ἄθἄνἄτος and other words—is obliged to put an artificial length upon tribrachic feet in order to get them admitted into the dactylic march of his verse; and how impossible it would have been to compose a long poem under the strict law of both quantitative and accentual conformity, we may see from the fact, that, in our own poetry, we have contented ourselves with fettering one of the elements and leaving the other free; that is to say, that, while we never, or very rarely, allow our spoken accent to clash with the rhythmical beat, we constantly take the liberty in our sung psalms and songs of drawing out short syllables to any length, and skipping over long ones with any amount of metrical celerity. Here, therefore, the Gordian knot is untied: the Greek poetry made to be sung is governed by quantity, the musical element of language; the modern poetry made to be read is governed by accent, the colloquial accent. What Nature, or rather the necessities of Art, have kept asunder, let no man bring together. Let no man imagine that colloquial accents, whether Greek or Roman, can possibly come into collision with the laws of a poetry so essentially musical in its character as the Greek.

3. But the ancients, it will be said, though their poetry was all musical in its birth, and a verse had no meaning except as sung, certainly did recite their poetry at an early period. Of course; and in this case it is obvious, that a

poetry constructed as part of the musical art was to a certain extent put out of Nature the moment it was translated into the region of spoken verse. In this case a collision between the musical beat and the accented syllables was unavoidable, and some sort of compromise would naturally be the result. This compromise, however, would on the whole be decidedly to the advantage of the musical rhythm, as opposed to the colloquial accent. For metre, as we have seen, was metre only in virtue of the regularly recurrent musical beat; and to abolish this was to destroy metre, and to turn verse into prose, as, in fact, we often hear English schoolboys do, when reading HORACE, and as the modern Greeks do when they read HOMER accentually. But that the ancients could not have done this is manifest both from the prominence of music in their national culture and from the effect of the rhythmical stroke in lengthening the shortest vowels, even in the verse of VIRGIL, which certainly was not sung. The poet who wrote

Liminaquē' laurusque Dei,

must have had his ear tuned to the march of a verse which gave that marked preponderance to the first syllable of a foot, which is musically given to the first note of a bar, and which allowed the license of lengthening a short vowel in such a position after the example of HOMER, specially before a word beginning with a liquid. MEETKERCHE and Voss were therefore right in reading classical verse mainly by this rhythmical beat, and practically disregarding the spoken accent. It does not follow, however, that though the rhythmical accent remained dominant even in spoken verse, it therefore exercised an exclusive sway. In many cases, of course, there would be no clash, and this, indeed, regularly happened in the two last feet of a Latin hexameter. But in other cases, where a clash did occur, the occasional bringing forward of the spoken accent might serve to break the monotony of a merely musical rhythm, and cause it to approach nearer to the march of dignified prose eloquence. Thus, the first line of VIRGIL may either be accented

Arma viumque canō' Trojæ' qui primus ab oris,

or

Arma viumque căn'ō Trō'jāe qui primus ab oris;

and in both cases the true quantities are preserved; but in the second method the spoken accent is allowed to control two words to the prejudice of the musical beat, by whose regular recurrence the hexameter verse was originally framed. In this way it was quite easy to recite Latin hexameters or Greek iambics in such a manner that, while the rhythmical beat mainly ruled, and no short syllable was ever heard where the music had a long note, the spoken accent to which the ear had been habituated in conversation did nevertheless generally shine through, and in special cases assert itself with that natural

emphasis which subordinates rhythm only to aid expression, and to prevent monotony.

4. It will now be evident how entirely Professor MUNRO was mistaken when he expressed surprise at the fact, that, while the rudest boor in the days of PLAUTUS was familiar with the exact laws of quantitative metre, even well-educated gentlemen of the middle class before the time of CONSTANTINE were apparently unable to write anything but accentual metre, constructed on the same principle as the Byzantine στίχοι πολιτικοί. The rudest boor, no doubt, could distinguish a long syllable from a short, and could discriminate the penultimate vowel in *păt'er* and *mā'ter* in a way that seems impossible to the gross ears of some of our English teachers. Our own peasants will distinguish *gŏt* from *goat*, or *god* from *goad*, exactly in the same way; but it will require more than a rhetorical flourish from CICERO to prove that the peasants of Italy, or even Attica, at any time were perfectly master of the complete doctrine of quantity as taught in the musical schools. For it must always be borne in mind that the practice of these schools was to a certain extent artificial; it was founded on certain concessions which the currency of common life had made to the necessities of art; and the common people, whose ears were trained mainly by the spoken accent, could not be expected either to compose verses in neglect of that accent, or to sympathise fully with its neglect in the case of verses composed by cultivated poets, except in so far as their own education had kept them in living connection with those schools of music from which the cultivated poetry had emanated. Now, in the best ages of Greece this living connection naturally existed; and the effect of custom and association would be such, that no other verses but those composed on the original quantitative principle would be recognised as legitimate even by the vulgar ear. But the moment that a great national decay commenced, and schools of popular culture were neglected, from that moment the common people, left to themselves, if ever they tried poetical composition, could do so only in obedience to the instinct which governs all poetry not intimately associated with the musical art. Poetry now became a species of measured conversation to which laws were given by the spoken accent, and where the fixed musical recurrence of long and short syllables was systematically ignored. In this change there is nothing strange or mysterious; on the contrary, it was the natural, and, we may say, necessary consequence of passing from a musical to a colloquial epoch in literature; and as a fleet-footed man, when he leaves the ice and takes off his skates, passes to a kind of locomotion governed by different conditions and subject to different laws, so a people, shaken loose from all musical tradition and left to form a poetry for itself, will infallibly fall upon a form of verse in which the musical value of vowels will be sacrificed to the familiar control of accentually preponderant syllables.

5. One word remains on the question of scholastic practice, which has

been such a bugbear to our teachers. Now, with regard to this problem, it is one of those to which, as GELDART says, the old adage applies, *solvitur ambulando.* What appears impossible in theory, is often easy in practice. If you wish to learn how to use your legs, just rise up and walk. If you imagine that there is any difficulty in saying Σωκρᾰ́τηϛ without saying Σωκρᾱ́τηϛ, or *bŏn'us* without saying *bōnus,* just put yourself under a master of elocution for five minutes, and you will shortly be drilled out of your difficulty. But why should the ears of teachers be haunted by such a hallucination as that by placing the Roman accent on the penult of all dissyllabic words, they are furnished with some sure spell against the violation of quantity? Is it not quite evident, rather, that the short quantity of the first syllable of βιός, a *bow,* is much more easily preserved by the natural oxytone accent than by the Latin accent βῐ́ος on the penult? And if the quantity of the long penult in the verb διατρῑ́βω is more effectively brought out by the accent on that syllable than if it had been on the last, is it not manifest that the same syllable, being short in the substantive διατρῐ́βή, is more certainly pronounced short—according to the argument of the Latinising Hellenists themselves—with the native oxytone accent than with the imported Latin one? Take, again, the word κᾰμάρᾱ, *a vault,* where all the vowels are doubtful, and where, of course, the quantity of each syllable can be recognised only by utterance. According to the current method, the accent, laid on the first syllable of this word, should inform me, that the syllable is long by virtue of the stress, and it does inform me also, if I am to believe my ears, that the other two syllables are short. But three parts of the information thus given are false; for the accent is not on the first syllable, and the quantity of the first syllable is short, and that of the last long. On the other hand, if I pronounce the same word according to the principles laid down in this paper, I learn not only where the accent is, but that the two first syllables are short, and the last long. The fact of the matter is, that, while the Greek accent, rightly placed, informs the ear rightly both as to the accent and the quantity of the syllables of which a word is composed, the Latin accent inverts and perverts both, and teaches, with regard to accent and quantity, only what must be unlearned. The opponents of accents, who absurdly call their Latinising method the quantitative pronunciation of Greek, ought to bear in mind that, in practical teaching, next to pronouncing the long syllables long and the short short, the best way to teach quantity is to pronounce the accent, which either stands upon the long syllable and favours its prolongation, or stands in such a definite relation to that syllable that the quantity of the unaccented syllable is known from the place of the accented.

But the great practical difficulty to which teachers allude is, perhaps, rather rhythmical than prosodiacal. The pronunciation of the Latin accent, says Mr CLARK, is the only way we have of teaching our pupils to appreciate the measure of classical verse. Abolish the Latin accentuation of Greek prose, and you turn the organ of HOMER into a hurdy-gurdy. Now, with regard to

this matter, I would observe, in the first place, that if the young gentlemen who usually come to our universities were to lose all the rhythmical appreciation of Greek verse that really lives in their ears, and not merely in their understanding, they would lose little that is worth keeping. For what are the facts of the case? The observation of the Latin accent facilitates the rhythmical reading of the two last feet of a hexameter verse; this is an accident of the Latin language, that is all. But not even in the reading of Latin does the reading, according to the Latin prose accents, prevent the constant occurrence of a clash between the spoken accent and the rhythmical beat. In the Ovidian pentameter such a clash must always occur twice, and in the two most marked places of the verse, And, if the absence of the oxytone accent causes this opposition in Latin, is it not strange that we should banish this same accent from its natural place on a Greek word, in order, as we say, to avoid, but actually in a great number of cases to produce, a collision between the rhythmical beat and that accent? Take, for instance, this second line from "the Wasps" of ARISTOPHANES—

"Φυλακὴν καταλύειν νυκτερινὴν διδάσκομεν,"

and it is plain that in the only two places where a clash does occur between the spoken accent and the rhythmical beat, according to the Latinised accent, that clash disappears the moment the words are read according to their natural Greek accentuation. And so, not only in Iambic verse, but in every verse whatever, the introduction of the Latin accent must jar with the rhythmical flow of the line wherever the rhythmical stroke falls, as it constantly does, on the last syllable of a word. This practical objection therefore vanishes in smoke. That gross-eared and ill-trained persons may be enabled to receive the harmonies of the two last feet in a Homeric line, with a little less trouble, or with no trouble at all, no wise educator can deem a sufficient reason for invading the whole inherited intonation of the finest language in the world, with sounds which, however proper on the banks of their native Tiber, on the banks of the Ilissus must be felt to be a gross barbarism. The rhythmical objection from the practical side is, in fact, only an ingenious apology to cover carelessness, to prop prejudice, and to mask with an attitude of apparent utility a pedagogic procedure, alike unscientific in principle and self-contradictory in practice.

Finally, if those who delight themselves in exaggerating imaginary difficulties have any honest desire to see how they disappear in the actual business of teaching, let them come to me; for I am a practical man, and speak from the experience of half a lifetime. I teach Greek on the principle that the ear is the natural and legitimate organ which must be addressed in the first place. I pronounce every word according to its just accent and quantity, allowing its own natural emphasis to sway the proper syllable of the Greek word, just as the Latin accent emphasizes the proper syllable of the Latin word, taking

special care at the same time that in no case shall the emphasis of the accent be drawn into a prolongation of a short vowel. In the matter of quantity, I allow length by position to be pronounced short, according to the English habit, partly because I do not feel sure that this length was anything but a metrical license unknown to prose, partly because I should not think it advisable to encumber the English lighthorseman with a greater weight of heavy Spondaic armour than he can conveniently carry. On the elevation of tone which naturally accompanies the stress, and indeed always seems to have done so at the end of a clause, I do not curiously insist, the accent being sufficiently marked without it. As little do I endeavour to distinguish between a long accented syllable, as in μήνη, and a circumflex, as in μᾶλλον, though I have not the slightest difficulty myself in bringing out the combination of rising and falling inflexion on the same syllable which the circumflex properly denotes. Thus, in the reading of prose, which should be continued assiduously for six months or a year before poetry is meddled with: I then take up Homer, and forthwith intimate to my students that, as the whole doctrine of Greek metres was a part of the science of music, it necessarily followed the laws of that science, and can be understood only by an entire subordination or sinking of the spoken accent in the first place, and a recitation according to the regularly recurrent beats of the rhythm. This, which teachers imagine to be so difficult, is one of the easiest things in the world. Most human beings have ears, and can beat time. Even serpents, and elephants, and dancing bears can do this. And in order that the rhythm may be thoroughly worked into the ear, I have no objection even to what may be called a little *sing-song* at starting; but the pupil, of course, as he advances, must be trained to counteract the monotony of mere rhythm by that variety which a proper attention to expression and punctuation produces. In this way, the whole perplexing and tedious doctrine of accent and quantity is learned from beginning to end by the ear; the pain of prosody becomes a pleasure; accent and quantity learn to observe their proper bounds, each, happy in his recognised domain, forgetting all thought of making a hostile invasion into the territory of the other. The only difficulty in the matter arises from the necessity of teaching a number of thoughtless and idle young men to unlearn all that lumber of false quantities and false accents which has either been systematically built up, or carelessly allowed to accumulate in the schools; but this is a difficulty which it is in the power of schoolmasters, and of schoolmasters alone, radically to remove. And I feel convinced that, so soon as a radical reform in this matter shall be seriously undertaken by teachers, not only will the inculcation of classical Greek be much facilitated, but the organs of utterance being rendered more flexible and more amenable to training, will accommodate themselves to the characteristic peculiarities of German, French, and other living orthoepies, with an aptitude the want of which is now so frequently lamented.

XIV.—*On the Average Quantity of Rain in Carlisle and the Neighbourhood.*

By Thomas Barnes, M.D., F.R.S.E.

(Read 17th April 1870.)

In the year 1827, I communicated to the Royal Society of Edinburgh some meteorological journals, kept at Carlisle by the late Mr Pitt, extending over a period of twenty-four years, viz., from 1801 to 1824 inclusive. An abstract of these journals, with explanatory remarks and tabular results, were drawn up by me, and read before the Society, and were afterwards published in their Transactions. I now beg to offer some remarks to the Society on journals kept by Dr Carlyle, in the city of Carlisle, from 1757 to 1783 inclusive, by the Rev. Jos. Golding at Aikbank, near Wigton, Cumberland, fourteen miles west of Carlisle, from 1792 to 1810 inclusive, and by myself at Bunkers Hill, two and a half miles west of Carlisle, which is situate 184 feet above the sea level, according to the late Ordnance Survey, from 1852 to 1870 inclusive. I shall confine my remarks to the quantity of rain that fell during the several periods of our journals. The accompanying tables show the quantity of each month and year included in these periods. I regret much that I am not able to give a description of the instruments used by Dr Carlyle and Mr Golding; but as they both were gentlemen of considerable ability and of liberal education, and devoted much time and attention to meteorology, there is no reason to doubt either the quality of their instruments or the correctness of their observations. Dr Carlyle's rain-gauge was placed in his garden, near the head of Abbey Street, and is about the same height as the ground on which the Cathedral stands, eighty-two feet above the level of the sea. My own rain-gauge consists of a copper funnel, twelve inches in diameter at the top, and is inserted into a strong tinned iron vessel, placed in a box on my garden wall, the height of the funnel being six feet above ground. It is examined from time to time, and particularly after a fall of rain. The water is measured by means of a glass tube of half an inch diameter, with an attached scale of inches and tenths. By this means, the rain that falls on a circular area of twelve inches diameter is collected on an area of half an inch diameter, so that inches and tenths in the tube correspond to $\frac{1}{576}$ and $\frac{1}{5760}$ of an inch of rain on the surface of the gauge. To prevent waste by evaporation, the communication between the funnel and the receiver is very narrow; and to prevent the rain that falls within the gauge from splashing over, the upper edge or rim of the funnel is turned upwards from the inclined direction of the under part, so as to stand vertically, and the

top of the gauge is parallel to the horizon. I have abstracted from the journals the quantity of rain that fell at Carlisle, Aikbank, and Bunkers Hill, during the periods they were kept, and have drawn up in a tabular form the quantity of rain for each month and year of these periods. I have also taken the averages of the observations, and have found some remarkable coincidences in the results. By these tables we observe the wet and dry months of every year for long series of years; we also observe the wet and dry years, and the wet and dry seasons of every year.

A TABLE EXHIBITING THE QUANTITY OF RAIN OF EACH MONTH AND YEAR, FOR TWENTY-SEVEN YEARS, TAKEN FROM THE METEOROLOGICAL JOURNAL OF THE LATE GEORGE CARLYLE, M.D., KEPT AT ABBEY STREET, CARLISLE, FROM 1757 TO 1783.

Years.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Quantity of each Year.
1757	·44	1·097	2·117	2·23	2·206	1·014	2·005	3·102	·544	1·457	2·703	1·111	20·026
1758	·832	2·9	1·319	1·59	1·152	·759	5·66	1·774	2·254	2·46	2·196	3·354	26·250
1759	1·348	·284	2·099	1·479	·668	3·773	1·76	2·368	3·016	4·137	1·494	·525	22·951
1760	1·722	2·519	·445	·687	1·106	2·795	·577	4·166	3·442	3·433	3·903	3·848	28·643
1761	·357	2·808	1·534	·96	1·925	2·322	2·617	1·976	5·079	1·432	3·698	1·735	26·443
1762	2·327	1·487	1·386	2·157	·905	·648	2·271	·96	4·393	1·348	2·296	·36	20·538
1763	·291	1·608	1·094	1·884	1·909	3·018	3·668	3·261	2·412	2·16	1·844	5·204	28·353
1764	4·181	2·538	1·497	·718	1·568	·772	2·764	2·097	1·897	2·565	2·525	1·04	24·162
1765	2·079	·596	3·343	2·368	·408	1·575	·386	2·195	1·903	2·147	1·572	·814	19·386
1766	·173	1·257	·259	1·371	2·927	3·316	2·241	1·794	2·948	2·566	1·541	1·079	21·472
1767	1·647	2·426	1·586	·211	3·41	·559	3·941	2·03	3·065	2·954	4·084	·624	26·537
1768	·893	6·504	·654	1·73	1·114	3·475	4·49	1·43	3·236	2·578	3·099	2·598	31·801
1769	1·016	1·557	·902	1·447	·886	1·753	1·488	3·427	5·138	1·37	1·242	1·577	21·803
1770	1·111	1·505	1·521	1·32	1·277	4·009	1·969	·831	3·8	1·299	2·77	3·71	25·122
1771	1·58	·476	·632	·805	1·894	·694	3·027	3·619	1·728	4·374	2·887	2·266	23·982
1772	1·365	1·398	1·8	·772	1·239	2·679	3·035	3·256	3·517	3·09	4·991	1·376	28·518
1773	2·927	1·24	1·077	1·993	1·897	·835	1·460	1·9	5·62	5·24	2·378	1·666	28·233
1774	2·01	2·222	·565	1·481	1·859	1·757	2·212	1·953	2·006	·737	·947	1·595	19·344
1775	3·136	2·958	2·099	·902	1·154	·645	2·857	3·903	3·489	4·104	2·58	1·305	29·132
1776	·625	2·373	·713	·59	·857	1·93	3·645	3·237	3·252	1·531	1·336	1·601	21·690
1777	·725	·69	1·152	1·593	1·1	3·308	2·606	2·771	·962	4·392	2·3	·416	22·015
1778	1·405	·691	1·861	·42	2·688	2·154	4·177	2·179	1·504	3·519	2·328	3·36	26·286
1779	·258	·626	·324	1·607	2·49	1·376	4·058	1·01	5·829	4·5	1·651	3·643	27·372
1780	·5	·988	2·303	1·799	2·137	1·347	2·043	·833	3·561	3·161	1·591	·722	20·985
1781	·824	2·081	·551	1·024	1·075	1·417	1·891	3·16	·833	·63	4·403	1·517	19·406
1782	3·531	·678	2·041	·767	2·104	1·362	1·674	4·229	3·392	3·608	·840	1·271	25·497
1783	2·076	1·774	·458	·17	1·931	1·981	2·11	3·676	3·592	2·743	1·684	·576	22·771
Totals for 27 years,	39·379	47·281	35·332	34·075	43·886	51·273	70·632	67·137	82·412	73·535	64·883	48·893	658·718
Means for 27 years	1·458	1·751	1·309	1·262	1·625	1·899	2·616	2·486	3·052	2·723	2·403	1·812	24·396

TABLE EXHIBITING THE QUANTITY OF RAIN OF EACH MONTH FOR NINETEEN YEARS, AND THE ANNUAL QUANTITY OF EACH YEAR, TAKEN FROM THE REV. JOSEPH GOLDING'S METEOROLOGICAL JOURNAL, KEPT AT AIKBANK, NEAR WIGTON, CUMBERLAND, FROM 1792 TO 1810.

Years.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Quantity of each Year.
1792	1·599	1·41	2·348	3·578	3·067	1·979	3·757	4·968	5·843	2·623	1·781	4·495	37·448
1793	1·388	4·1	2·405	·901	1·620	2·095	1·594	5·328	1·617	2·426	2·034	2·988	28·496
1794	2·594	4·255	1·426	3·357	1·948	·995	2·564	2·594	3·207	4·813	2·675	2·862	33·290
1795	·682	3·505	3·256	2·503	1·342	3·377	1·836	4·117	·674	6·216	6·830	6·022	40·360
1796	6·505	2·502	·928	1·559	3·515	3·31	5·633	1·192	3·027	3·558	1·988	1·627	35·344
1797	3·776	·655	1·437	1·646	3·757	1·921	4·146	4·336	5·668	3·239	3·534	4·458	38·573
1798	3·294	2·715	1·401	1·671	1·15	1·193	4·604	3·053	3·349	3·775	2·847	1·731	30·783
1799	2·781	2·379	1·276	2·717	2·357	·558	3·657	8·476	5·228	4·777	3·916	·242	38·364
1800	3·267	·880	2·368	3·499	3·559	·647	1·641	1·362	4·659	5·243	4·813	1·929	33·867
1801	3·117	3·953	4·898	1·19	1·257	·318	5·544	·857	4·459	5·321	2·394	3·915	37·223
1802	2·564	3·429	1·611	3·441	·394	2·627	6·883	3·368	2·597	5·199	·501	3·260	35·874
1803	1·398	3·007	1·734	1·849	4·612	3·41	·694	3·794	3·17	2·158	2·715	3·192	31·733
1804	6·101	1·695	2·543	1·811	2·189	2·164	1·758	4·324	2·013	5·699	2·028	1·463	33·788
1805	2·934	3·404	2·769	·946	1·75	2·938	3·628	2·31	3·011	·235	·547	4·869	29·341
1806	4·88	2·669	·73	1·253	1·744	1·956	3·97	6·896	4·87	1·639	5·424	5·18	41·211
1807	1·385	4·77	·967	2·129	3·069	1·628	4·246	3·179	6·415	4·16	3·893	2·743	38·584
1808	3·839	1·595	·267	1·662	2·942	1·773	3·269	3·816	2·103	5·162	3·478	1·886	31·792
1809	3·963	2·967	·636	·887	4·547	3·194	2·194	7·386	4·036	·562	1·525	5·492	37·389
1810	1·886	1·348	5·123	·719	·642	1·386	5·174	3·046	1·254	3·033	2·976	3·771	30·358
Totals for 19 years	57·953	51·238	38·123	37·318	45·461	37·469	66·792	74·402	67·200	69·838	55·899	62·125	663·818
Means for 19 years	3·05	2·697	2·006	1·964	2·393	1·972	3·515	3·916	3·537	3·676	2·942	3·27	34·938

It is worthy of remark that Dr MILLER states in his "Synopsis of the Fall of Rain, &c., in the English Lake and Mountain District in the year 1853," that—"Among several abnormal and opposite atmospheric conditions presented by the years 1852 and 1853, the departure from the average in the rain fall is the most obvious and remarkable. While the former was the wettest, the latter was the driest year since the experiments were begun in 1844. In 1852 the depth of water precipitated at Seathwaite was equivalent to 156·74 inches, and, in 1853, to 113·69 inches—a difference of 43 inches, corresponding to the average annual fall at Whitehaven in the last ten years." A similar departure from the average rain-fall took place at Bunkers Hill—the greatest fall during the period of my journal being in 1852, and the least in 1853, as appears by the accompanying Table—31·825 inches in the former year, and 19·613 inches in the latter.

A TABLE EXHIBITING THE QUANTITY OF RAIN OF EACH MONTH FOR NINETEEN YEARS, AND THE ANNUAL QUANTITY OF EACH YEAR, TAKEN FROM A METEOROLOGICAL JOURNAL KEPT AT BUNKERS HILL, NEAR CARLISLE, BY THOMAS BARNES, M.D., FROM 1852 TO 1870.

Years.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual quantity of each year.
1852	3·571	1·360	·625	1·189	2·363	4·88	2·114	3·446	1·947	2·694	2·192	5·444	31·825
1853	3·033	·732	·621	1·303	·881	2·151	2·814	1·904	2·07	2·351	1·243	·51	19·613
1854	1·665	·788	·81	·072	3·43	3·447	1·501	3·277	1·817	2·326	1·895	2·178	23·206
1855	·097	·746	1·449	1·442	1·486	2·718	2·819	3·098	1·197	4·322	1·375	·598	21·347
1856	2·072	1·843	·062	1·152	2·829	3·906	1·277	4·140	2·175	2·706	1·137	3·618	26·917
1857	1·657	·753	2·47	1·18	1·138	2·413	2·347	1·934	2·895	2·263	2·09	2·003	23·143
1858	1·027	·458	1·75	1·055	2·965	2·157	3·402	3·276	3·718	3·072	1·158	1·75	25·788
1859	2·004	1·222	2·59	1·984	·05	1·531	3·111	2·407	4·185	1·378	3·611	2·361	26·434
1860	3·381	·854	2·588	1·187	1·807	3·114	1·4	3·684	1·06	4·5	1·25	2·187	27·012
1861	1·093	1·42	2·944	·564	1·223	1·916	4·02	3·407	4·623	1·815	6·704	1·935	31·664
1862	2·593	·781	1·756	2·218	3·066	2·854	4·159	3·469	2·609	4·145	1·698	2·312	31·66
1863	3·572	1·371	·468	2·593	2·376	2·61	·625	2·583	4·711	4·003	3·177	2·274	30·363
1864	2·0	1·781	2·966	1·156	1·868	2·388	·541	1·72	4·607	3·407	1·921	1·935	26·29
1865	1·374	1·656	1·093	·796	4·311	·783	1·097	3·671	·89	5·0	2·631	1·412	24·714
1866	3·772	2·184	1·593	·684	1·064	1·937	2·967	4·0	3·965	1·281	3·592	3·457	30·496
1867	2·281	1·718	1·407	2·92	2·49	1·16	3·416	1·665	2·31	1·857	·577	1·27	23·07
1868	2·393	2·01	3·355	2·5	1·993	·986	·281	3·125	2·116	2·187	1·646	4·408	27·0
1869	2·225	3·062	·468	1·871	2·02	1·17	·743	·871	4·25	1·92	3·057	2·239	23·89
1870	2·673	1·7	·468	·998	1·354	1·629	·859	2·333	1·436	3·868	2·21	·972	20·5
Totals for 19 years,	42·483	26·439	29·483	26·864	38·714	43·75	39·493	54·01	52·581	55·095	43·164	42·863	494·93
Means for 19 years,	2·236	1·391	1·552	1·414	2·037	2·303	2·078	2·843	2·767	2·9	2·272	2·256	26·04

The Tables from Dr CARLYLE's and Mr GOLDING's Journals, I made nearly forty years ago, but they were never published. Mr GOLDING set a great value upon his Journals, and, for their safe keeping, gave them into the custody of the Rev. RICHARD MATTHEWS of Wigton Hall, with a request that he would place them in his library. Mr MATTHEWS died many years ago; his library was sold after his death; and Mr GOLDING's Journals disappeared. They have probably been torn up as waste paper. Dr CARLYLE's family are all dead, and what has become of his Journals I know not.

On comparing the averages of our observations with those of Mr PITT, which I have also added, I find in three out of four, viz.—in Dr CARLYLE's, Mr GOLDING's, and Mr PITT's, April to be the driest month of the year. According to my own, February was the driest, and April stands next on the list. July, August, September, and October were wet months, according to all the Journals.

The following are the averages or mean quantities of rain for the several months of the year, during the different periods. They are arranged in the progressive order of the increasing quantity of rain in each month, according to

the several Journals, beginning with the driest month, and proceeding to the wet months :—

Dr Carlyle's Journal. 27 Years Mean.		Mr Golding's Journal. 19 Years Mean.		Mr Pitt's Journal. 24 Years Mean.		Dr Barnes' Journal. 19 Years Mean.	
	Inches.		Inches.		Inches.		Inches.
April,	1·262	April,	1·964	April,	1·56	February,	1·391
March,	1·309	June,	1·972	June,	1·96	April,	1·414
January,	1·458	March,	2·006	January,	2·128	March,	1·552
May,	1·625	May,	2·393	March,	2·209	May,	2·037
February,	1·751	February,	2·697	February,	2·308	July,	2·078
December,	1·812	November,	2·942	May,	2·355	January,	2·236
June,	1·899	January,	3·05	November,	2·797	December,	2·256
November,	2·403	December,	3·27	December,	2·809	November,	2·272
August,	2·486	July,	3·515	September,	2·827	June,	2·303
July,	2·616	September,	3·537	October,	3·061	September,	2·767
October,	2·723	October,	3·676	August,	3·24	August,	2·843
September,	3·052	August,	3·916	July,	3·317	October,	2·9

From the averages it appears that about twice as much rain falls in each of the latter months of the Table, as in the month of April; and about one-third less rain falls in the first six months of the year, than in the last six months.

This distribution of rain answers wise and important purposes in the economy of nature. Were the reverse the case, *i.e.* did more rain fall in spring than in autumn or winter, very disastrous consequences would ensue. The great benefit of dry weather in spring to agriculture is obvious; the value of an ounce of March dust is proverbial. The great fall of rain in the latter months of the year may, I think, in some measure be accounted for by the cold increasing as the sun recedes from us in autumn, and the vapours, which had been raised by the heat of summer, are then condensed and precipitated in the form of rain.

Mr Golding, whom I had the pleasure of numbering among my friends, on seeing the comparative Table I had drawn up of the mean quantities of rain for the several months of the year, made the following remarks :—

"This mode of exhibiting the subject is both curious and useful; and notwithstanding the great attention which I formerly paid to the phenomena of the weather, I confess that till now I never knew that April was the driest month of the year. April showers are so frequently mentioned as to give a general idea that it is rather a wet month than otherwise; but it may be remarked that the showers in April are seldom stormy, or attended with great falls of rain, as some of the summer months are after the solstice is turned. This dryness of April is most probably occasioned by the less development of the electric fluid at that particular season of the year; for when by means of the summer heats the air begins to be more strongly electrified, then it is that the showers become heavy, and often send down immense quantities of rain in a very short space of time. This it is which makes July and August generally the wettest months of the year; and happy it is for us poor mortals, that such is the

arrangement of nature; for if there were not very heavy falls of rain during the excessive heats of summer, the ground would be exhausted of moisture, and vegetation entirely at a stand."

There is a remarkable difference between the Journals of the late Dr CARLYLE and Mr PITT, in regard to the mean annual quantity of rain. Both Journals were kept at Carlisle, and both of the gentlemen, I have reason to believe, were careful and accurate observers. According to Dr CARLYLE's Journal, the average annual quantity of rain is 24·396 inches, and according to Mr PITT's it is 30·571 inches. How is this to be accounted for? Has the climate of this country undergone some change? It is evident from an inspection of the Journals, or of the Tables formed from them, that the quantity of rain is different in different years, and that sometimes there are a few wet years and sometimes a few dry years in succession. Is this the case with long periods of time? So that Dr CARLYLE's Journal may have been kept when there was a dry series of years, and Mr PITT's when there was a wet series? Perhaps the difference may be explained by their rain-gauges being placed in different situations. Dr CARLYLE's gauge was placed at the head of Abbey Street, 82 feet above the sea-level, higher than Mr PITT's, which was kept in Shaddongate, 40 feet above the sea-level. It has been frequently remarked, that when one rain-gauge is placed on the top of a high tower, and another at the bottom, more rain falls into the lower gauge than into the higher one. But there is another reason which may be assigned for the difference. The situation of Dr CARLYLE's rain-gauge was in the vicinity of his dwelling-house, which would occasionally prevent some rain falling into the gauge. It was placed on a wall on the S.W. side of his house. This I am inclined to consider the principal cause of the difference of the two Journals. Still the difference of altitude between Abbey Street and Shaddongate might have considerable effect, and may in some measure account for the different results. These causes, however, would have very little influence on the comparative monthly averages of the fall of rain.

The Cumberland Infirmary stands on elevated ground on the S. side of the river Eden, 30 feet above the bed of the river, and about one mile N.W. of my garden at Carlisle, which is nearly of the same height as the site of the Cathedral. For several years I kept a rain-gauge at each place, constructed on the plan recommended in BREWSTER's Cyclopedia, and I always found a greater fall of rain at the former than at the latter place. The following is the quantity registered at each place in the years 1837 and 1838, and shows the difference of rain-fall at these two places in these years :—

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual quantity of each year.
1837													
rmary, .	2·278	1·866	·91	·535	1·0	2·38	5·537	4·53	2·28	3·12	3·17	3·66	30·972
den in astle St.,	1·59	3·16	1·02	1·2	1·13	2·23	4·37	1·67	·98	2·9	·82	1·78	22·85
1838													
rmary, .	1·215	·59	2·436	1·51	1·49	4·69	3·195	3·45	2·28	2·65	2·47	·78	26·756
den in astle St.,	1·05	·09	·976	1·384	1·69	3·172	1·85	1·08	1·035	1·38	1·4	1·15	16·257

With regard to the difference that exists between the annual mean quantity of rain of Mr GOLDING's and Mr PITT's Journals, Mr GOLDING's being 4·4 inches more than Mr PITT's, I shall give you the explanation of the former gentleman in his own words, contained in a letter written by him many years ago :—

"I find that the annual quantity of rain, according to my diary, is somewhat greater than that shewn by Mr PITT's; and this might naturally be expected from the difference of situation, for my observations were chiefly made at Aikbank, which borders on the hilly part of the country,—and it is well known that in a hilly, and more especially in a mountainous district, there is much more rain than in a level one. Besides, Carlisle has a further cause of exemption from rain :—It lies nearly in the direction of the Solway Firth, and when storms come from off the Irish Sea, as they frequently do, the vapour on entering the Firth is attracted either by the Scotch or the English mountains, which will occasion more rain to fall on each side of the Firth, than in the direction of the Firth itself."

FIG. 1.

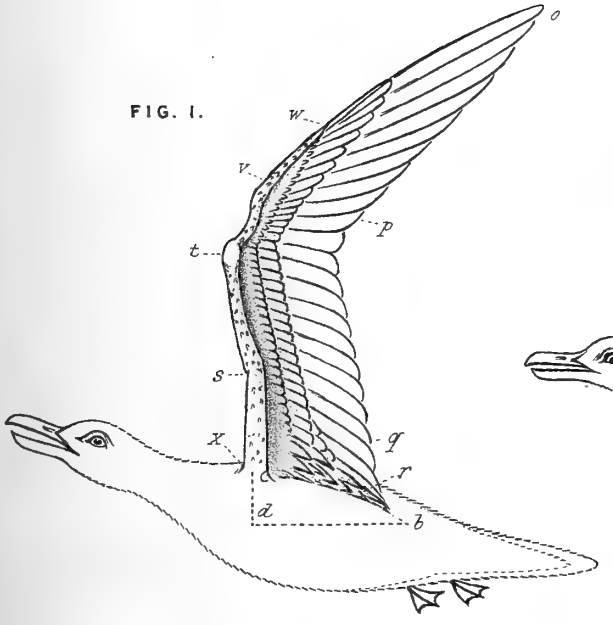


FIG. 2.

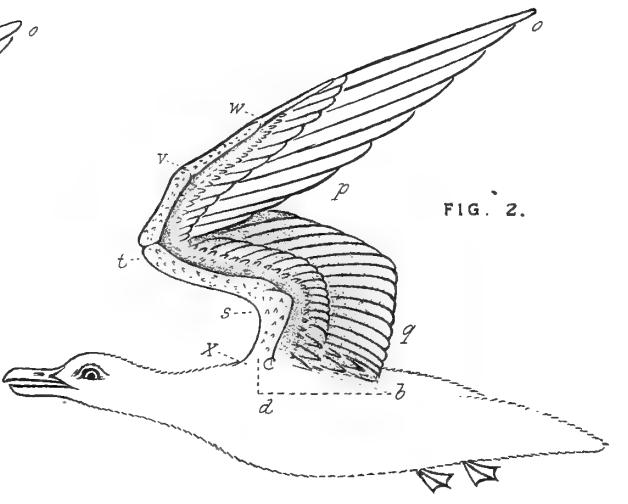


FIG. 3.

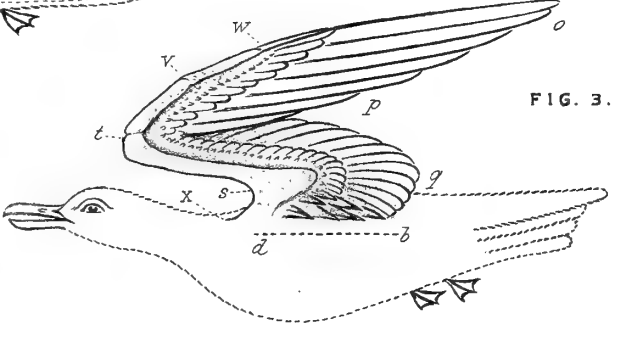


FIG. 4.

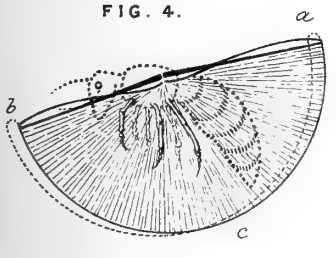


FIG. 5.

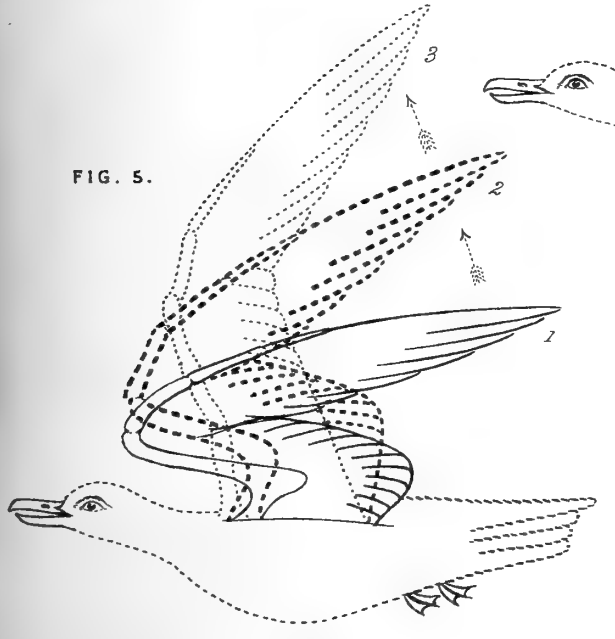
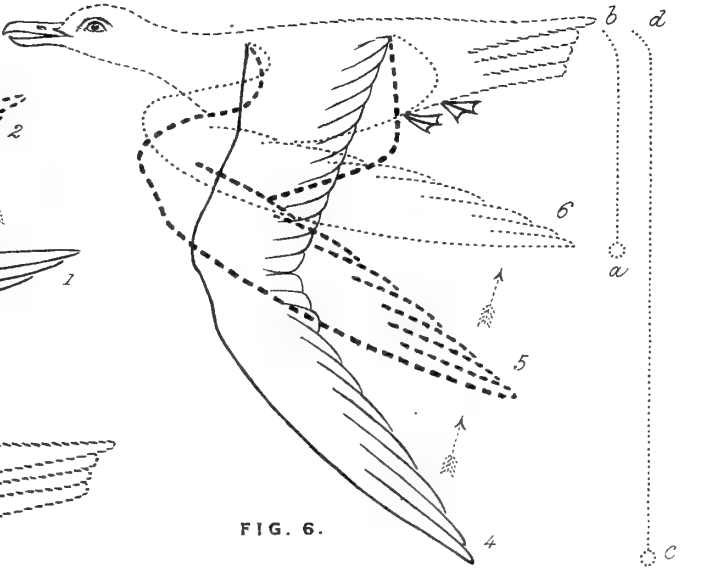


FIG. 6.



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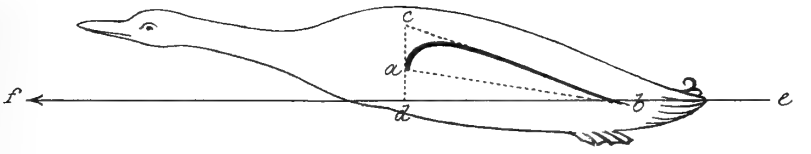

FIG. 7.

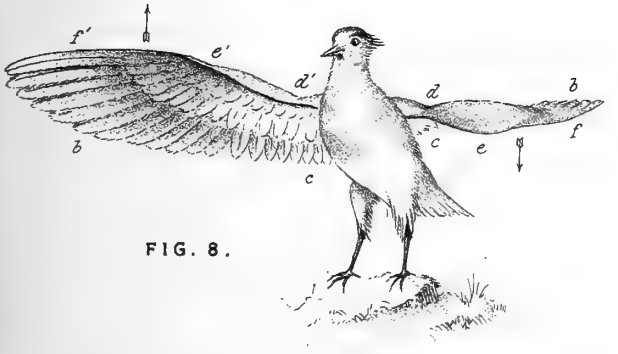

FIG. 8.

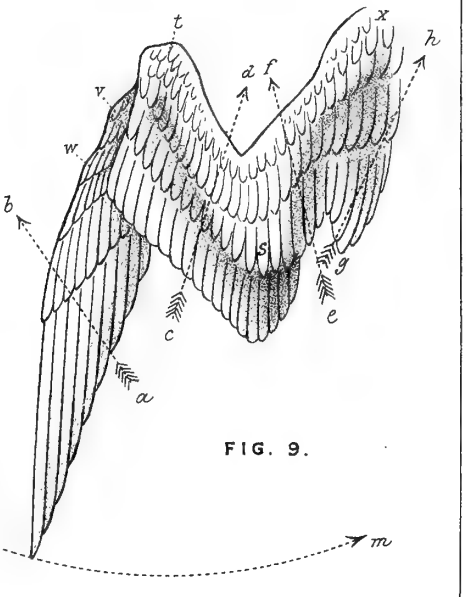

FIG. 9.

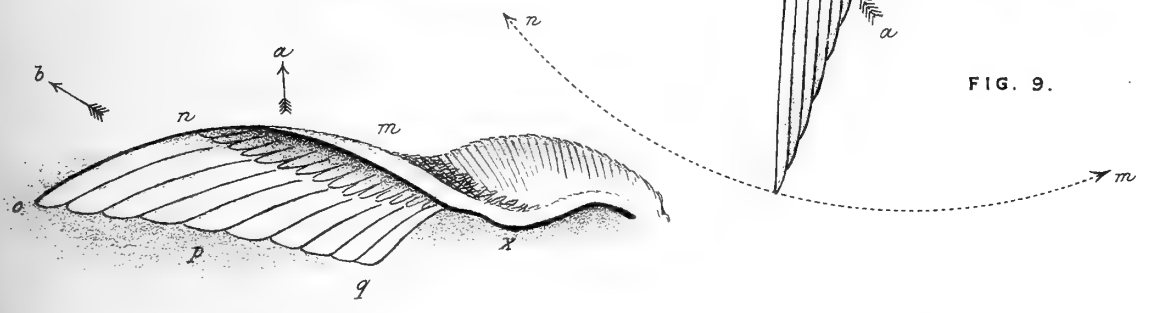

FIG. 12.

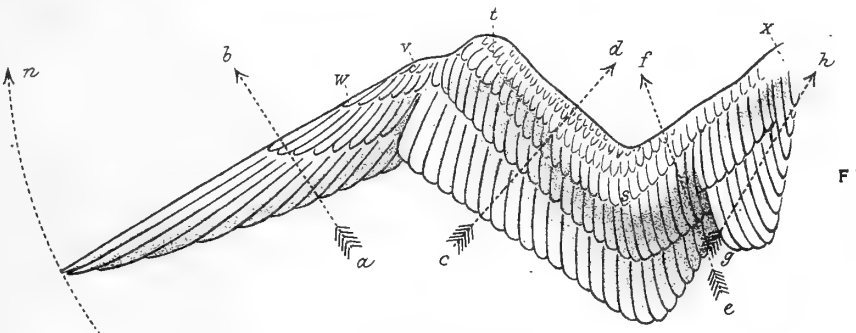

FIG. 10.

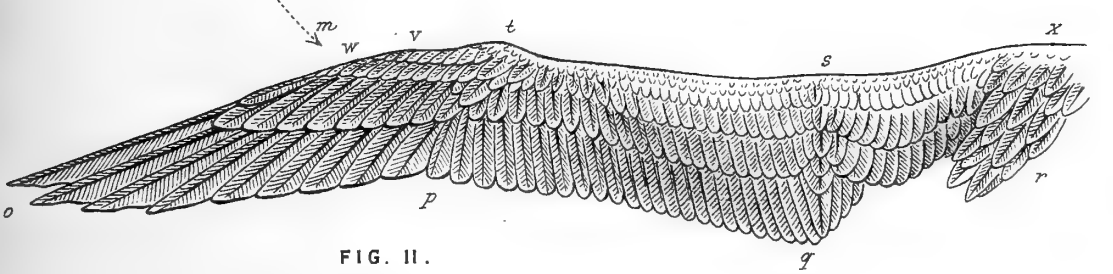

FIG. 11.

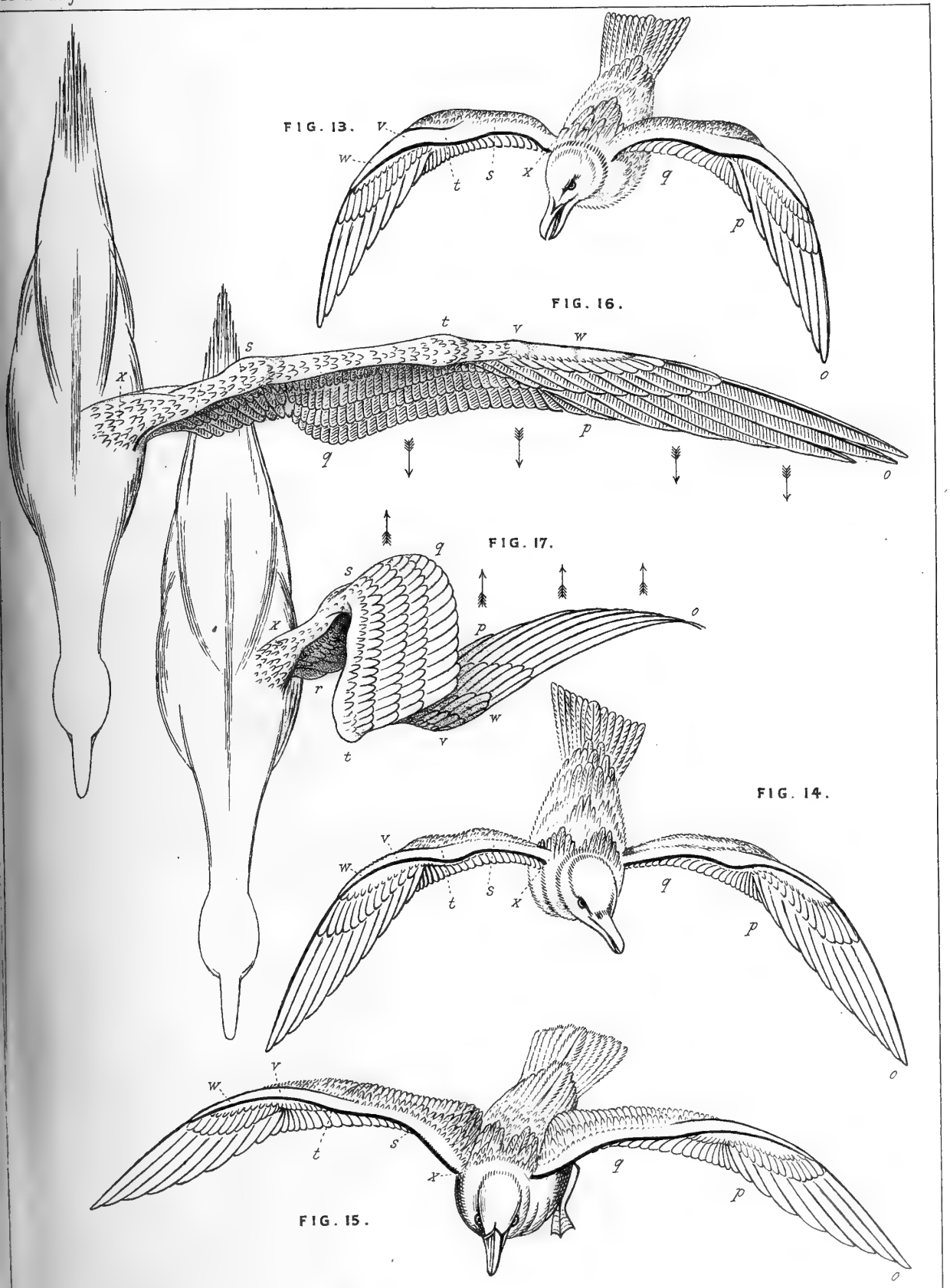

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FIG. 18.

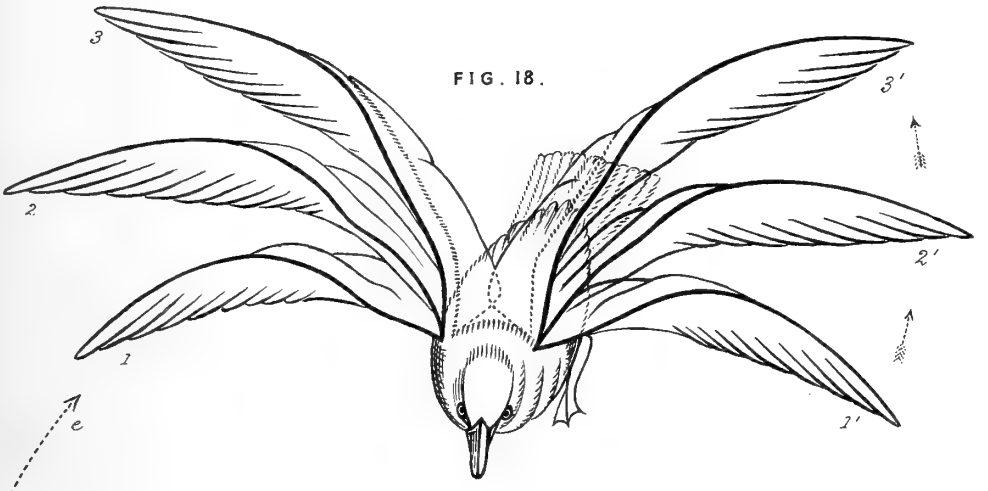

FIG. 19.

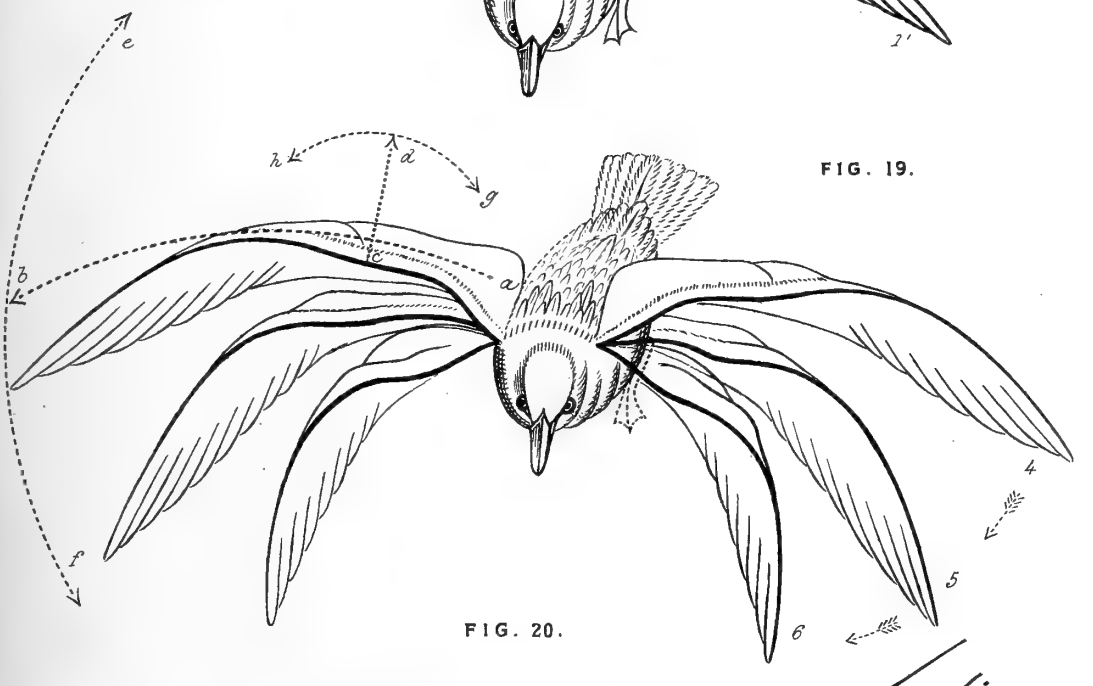

FIG. 20.

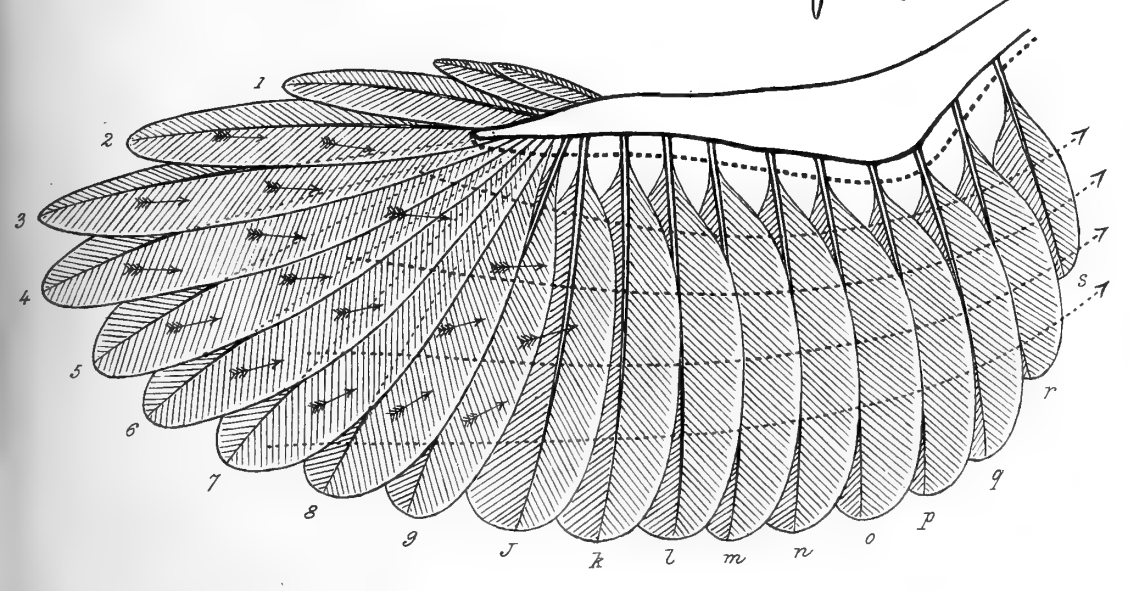

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FIG. 21.

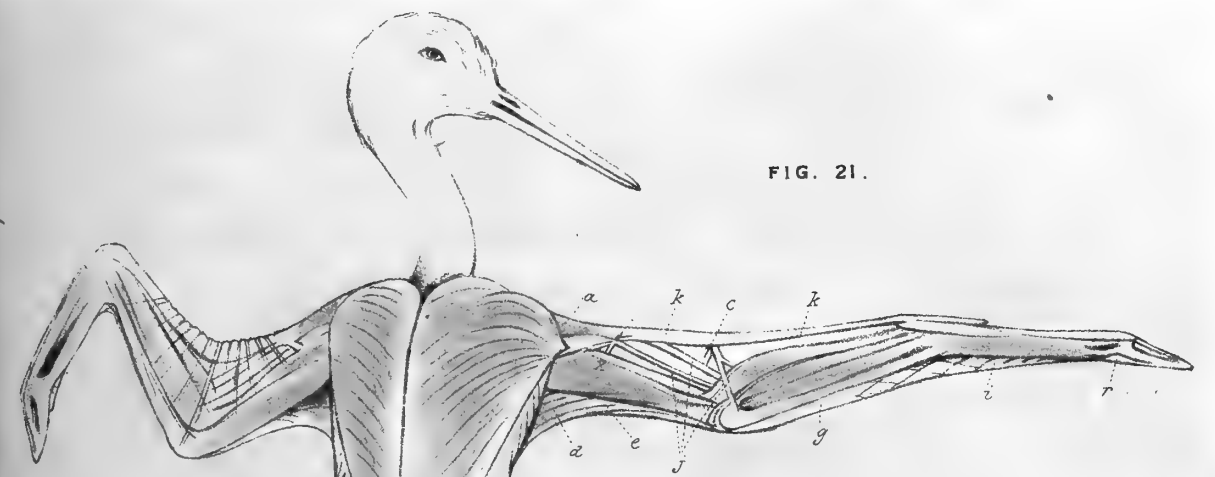

FIG. 22.

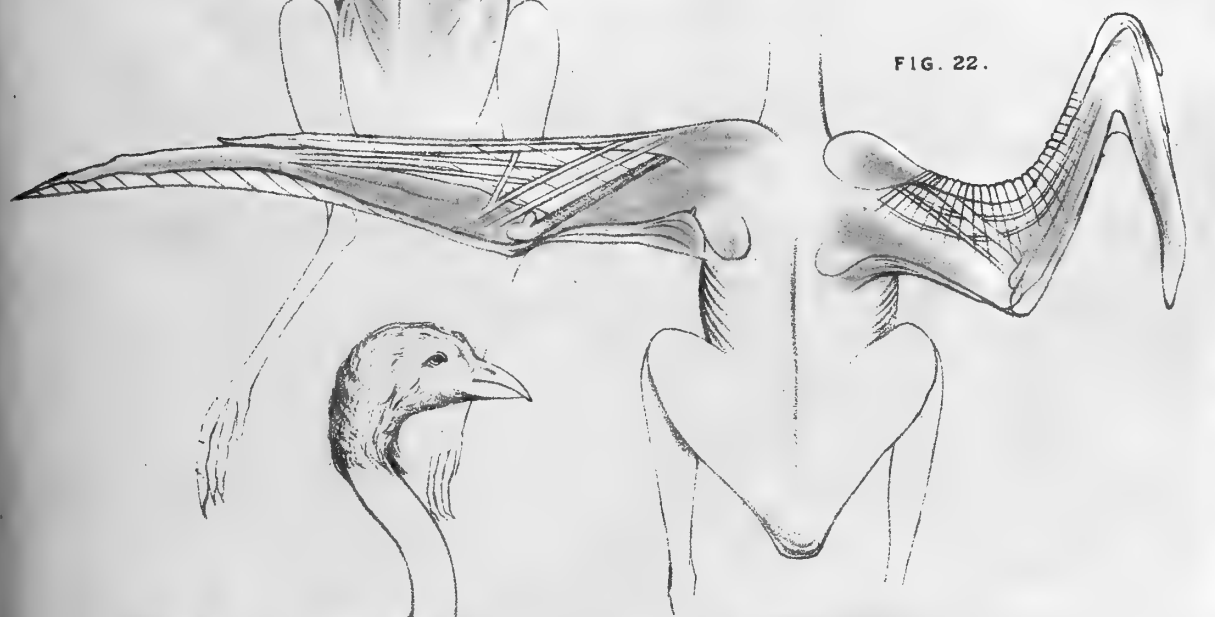

FIG. 23.

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FIG. 24.

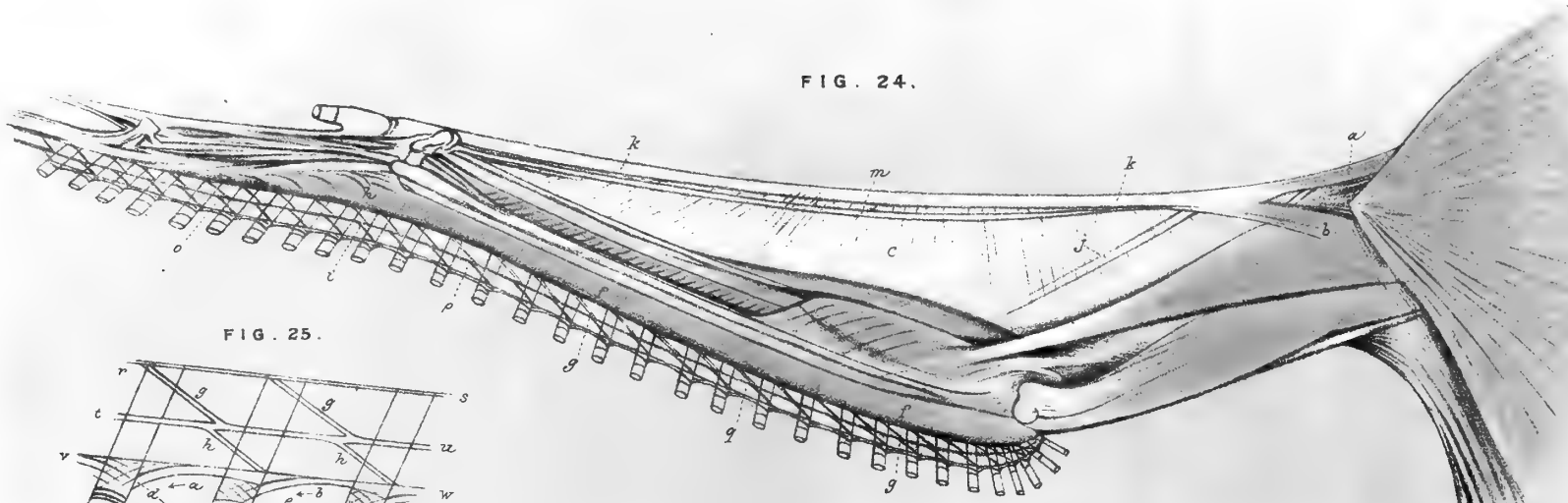


FIG. 25.

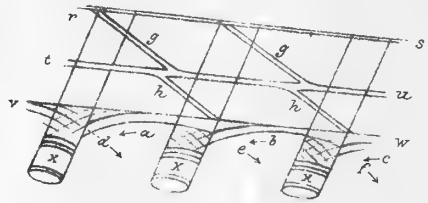
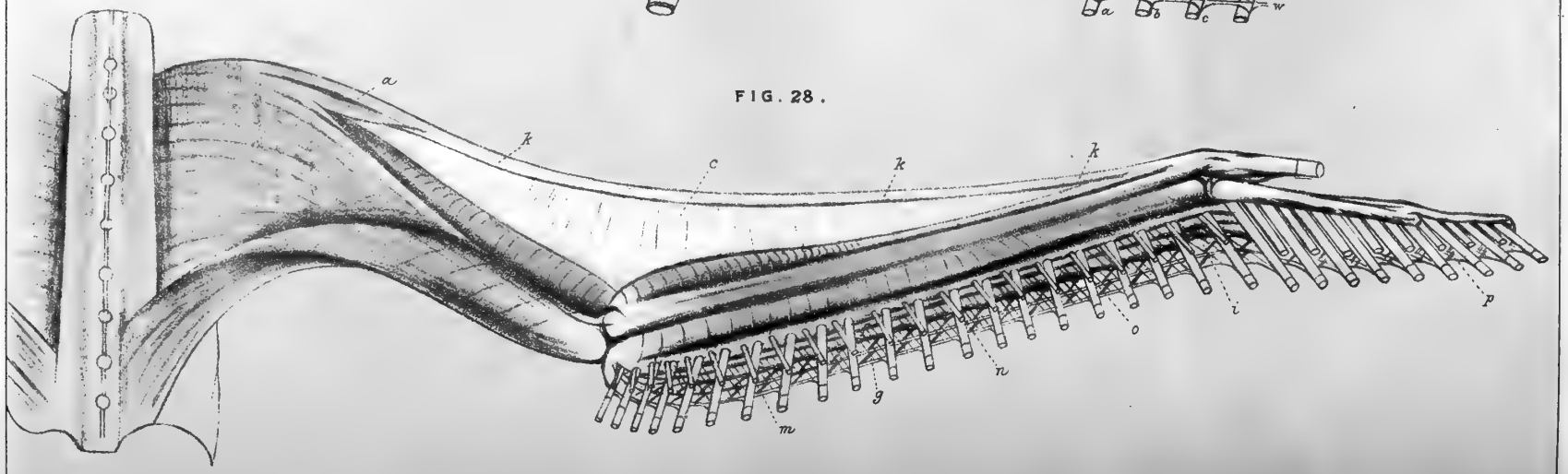


FIG. 26.

FIG. 27.

FIG. 28.



J. Bell Pettigrew, M.D. del.t
W. H. Mc Farlane, Luth.r Edin.r

XV.—*On the Physiology of Wings, being an Analysis of the Movements by which Flight is produced in the Insect, Bat, and Bird.* By James Bell Pettigrew, M.D., F.R.S., Pathologist to the Royal Infirmary of Edinburgh, and Curator of the Museum of the Royal College of Surgeons of Edinburgh. Communicated by Professor Turner. (Plates XI. to XVI.)

(Received 2d August 1870. Read 16th January 1871.)

INTRODUCTORY REMARKS.

(*For Table of Contents see end of Memoir.*)

In order to determine with exactitude the movements made by the wings in flight, and the part which the air plays in modifying them, I was induced several years ago to collect a large number of facts, and to undertake an extensive series of experiments with natural and artificial wings. My observations and experiments, I may remark, were not wholly confined to flight. On the contrary, I traced the analogy between flying, swimming, and walking; a circumstance which compelled me to pay particular attention to the size, shape, and movements, not only of wings, but also of the travelling surfaces of quadrupeds, amphibia, and fishes. By adopting this method, I obtained suggestions which have proved of the utmost importance to me in my attempts at elucidating the very intricate problem of flight.

As there are, strictly speaking, only three highways in nature (the land, the water, and the air), so there are three principal varieties of locomotion. There are, however, a limited number of mixed forms, the animal in such cases being furnished with travelling surfaces, modified in such a manner as to enable it to progress upon, or in, two essentially different media. The mixed movements are alike interesting and instructive, as they prove that movements apparently very dissimilar are in reality only links of a great chain of motion, which drags its weary length over the land, through the water, and extends skyward. That, therefore, is not wanting which connects the motions peculiar to walking animals with those peculiar to swimming and flying animals. Thus the seal furnishes the link between the land and water, and the galeopithecus between the land and air; while the flying fish supplies the link between the water and the air.

On making a careful examination of the structure and movements of the

great pectoral fins or pseudo-wings of the flying fish, I felt persuaded that a close analogy existed between the flippers, fins, and tails of sea mammals and fishes on the one hand, and the wings of insects, bats, and birds on the other; in fact, that theoretically and practically these organs one and all formed flexible helices or screws, which, in virtue of their rapid reciprocating action, operated upon the water and air after the manner of double inclined planes.

Guided by these indications, I especially directed my attention to the twisting flail-like movements of the wings of insects; of the flippers and tails of sea mammals, and of the fins and tails of fishes. These I found all acted upon the air and water by curved surfaces, the curved surfaces reversing, reciprocating, and engendering a wave pressure, which could be continued indefinitely at the will of the animal.

In order to prove that sea-mammals and fishes swim, and insects, bats, and birds fly, by the aid of curved figure of 8 surfaces, which exert an intermittent wave pressure, I constructed artificial fins, flippers, and wings, which curved and tapered in every direction, and which were flexible and elastic, particularly towards the tips and posterior margins. These fins, flippers, and wings were slightly twisted upon themselves, and when applied to the water and air by a sculling or figure of 8 motion, curiously enough not only reproduced the curved surfaces referred to, but all the other movements peculiar to the fins and tail of the fish when swimming, and to the wings of the insect, bat, and bird when flying.

History of the Figure of 8 or Wave Theory of Flying.

The Wing a Twisted Lever or Helix.—I announced this view in a lecture delivered at the Royal Institution of Great Britain in the early part of 1867. An abstract of the lecture appeared in the Proceedings of the Institution under date the 22d of March 1867.* At pages 99, 100, and 101 of the abstract in question, the spiral conformation of the wing in the insect and bird is adverted to at length, and there described as a twisted lever or helix, which owes its peculiar elevating and propelling power in a great measure to its shape. Particular emphasis is also placed upon the partial rotation of the wing on its long axis during extension and flexion, and to its screwing and unscrewing action during the down and up strokes, this being a "*sine qua non*" in flight. In the pages alluded to, the subjoined passages occur:—"The wings of insects and birds are, as a rule, more or less triangular in shape, the base of the triangle being directed towards the body, the sides anteriorly and posteriorly. They are also conical on section from within outwards and from before backwards; this shape converting the pinion into a delicately graduated instrument, balanced with the utmost nicety to satisfy the requirements of the muscular system on

* On the Various Modes of Flight in relation to Aëronautics.

the one hand, and the resistance and resiliency of the air on the other. . . . The neuræ or nervures in the insect's wing are arranged at the axis or root of the pinion, after the manner of a fan or spiral stair; the anterior one occupying a higher position than that farther back, and so of the others. As this arrangement extends also to the margins, the wings are more or less twisted upon themselves, and present a certain degree of convexity on their superior or upper surface, and a corresponding concavity on their inferior or under surface; their free edges supplying those fine curves which act with such efficacy upon the air, in obtaining the maximum of resistance and the minimum of displacement; or what is the same thing, the maximum of support with the minimum of slip. . . . . All wings obtain their leverage by presenting oblique surfaces to the air, the degree of obliquity gradually increasing in a direction from behind forwards and downwards during extension, when the sudden or effective stroke is being given, and gradually decreasing in an opposite direction during flexion, or when the wing is being more slowly recovered preparatory to making a second stroke. The effective stroke in insects, and this holds true also of birds, is therefore delivered downwards and forwards, and not as the majority of writers believe, vertically, or even slightly backwards. . . . . To confer on the wing the multiplicity of movement which it requires, it is supplied at its root with a double hinge or compound joint, which enables it to move not only in an upward, downward, forward, and backward direction, but also at various intermediate degrees of obliquity. . . . The wing of the bird, like that of the insect, is concavo-convex, and more or less twisted upon itself. The twisting is in a great measure owing to the manner in which the bones of the wing are twisted upon themselves, and the spiral nature of their articular surfaces, the long axes of the joints always intersecting each other at nearly right angles. As a result of this disposition of the articular surfaces, the wing may be shot out or extended, and retracted or flexed in nearly the same plane, the bones of the wing rotating in the direction of their length during either movement. This secondary action, or the revolving of the component bones upon their own axes, is of the greatest importance in the movements of the wing, as it communicates to the hand and forearm, and consequently to the primary and secondary feathers which they bear, the precise angles necessary for flight. It, in fact, insures that the wing, and the curtain or fringe of the wing, which the primary and secondary feathers form, shall be screwed into and down upon the wind in extension, and unscrewed or withdrawn from the wind during flexion. The wing of the bird may therefore be compared to a huge gimlet or auger, the axis of the gimlet representing the bones of the wing; the flanges or spiral thread of the gimlet the primary and secondary feathers."

The lecture referred to formed part of a memoir which was communi-

cated by Professor HUXLEY to the Linnean Society, and read before that body on the 6th and 20th of June 1867. It is published *in extenso* in the 26th volume of the Transactions of the Society, with upwards of eighty illustrations.*

The principal object of the memoir is to establish an analogy between the walking surfaces of quadrupeds, the swimming surfaces of fishes, and the flying surfaces of insects, bats, and birds. These are all described† and figured‡ as twisted levers or screws in an anatomical sense (pages 361 and 362, figures 37, 38, 39, and 40), and as flexible reversing screws in a functional or physiological sense (pages 336 and 362, figures 2, 41, 42, and 43).§ As a consequence, the quadruped and biped‖ are represented as walking,¶ and the seal and

* On the Mechanical Appliances by which Flight is attained in the Animal Kingdom, &c.

† *Op. cit.*, from page 199 to page 267 inclusive.

‡ *Op. cit.*, Plate XV. figs. 49, 51, 57, 68, 69, 70. Likewise Diagram 18 A *d'e'f'*, *a'b'*, page 253.

§ *Op. cit.*, Plate XV. figs. 58, 59, 61, 73, 74, and 75.

‖ *Op. cit.*, Plate XV. fig. 78.

¶ I think it proper to state that various anatomists have carefully examined the form of the articular surfaces of the joints in the limbs, more especially in man. The researches of the brothers WEBER and Professor MEYER of Zurich are so well known, that it may suffice simply to refer to them. I would also direct attention to the writings of LANGER, HENKE, MEISSNER, and the late Professor GOODSIR. LANGER, HENKE, and MEISSNER succeeded in demonstrating the "screw configuration" of the articular surfaces of the elbow, ankle, and calcaneo-astragaloid joints, and GOODSIR showed that the articular surfaces of the knee-joint consist of "a double conical screw combination." The last-named observer also expressed his belief, "that articular combinations, with opposite windings on opposite sides of the body, similar to those in the knee-joint, exist in the ankle and tarsal, and in the elbow and carpal joints; and that the hip and shoulder joints consist of single-threaded couples, but also with opposite windings on opposite sides of the body." The following are the views of LANGER as interpreted by GOODSIR :—(Proc. Roy. Soc. Edin., Jan. 18, 1858, and Anatomical Memoirs, vol. ii. p. 231.) "LANGER, acting on the happy idea of prolonging the screw by uniting, in one direction, a number of plaster casts of the same articular surface, succeeded in forming continued screws from the upper articular surface of the astragalus in the horse, panther, and human subject. LANGER concludes that the 'go line' (a line obtained from the scratch of a steel point fixed on one of the articular surfaces, and which marks the opposite surface when the joint is moved) of the ankle-joint in all the mammalia is a portion of a helix, and that therefore the astragaloid surface is a segment of a cylindrical or conical male screw, while the tibio-fibular surface is a segment of the corresponding female screw. The right ankle-joint is a left-handed screw combination; the left ankle-joint a right-handed. When therefore the foot is conceived to be fixed, the leg, in passing from a position of extension to flexion, moves laterally outwards along the axis of rotation, and the sine of the angle of inclination of the thread—that is, in proportion to the extent of flexion and the rapidity of the screw." GOODSIR, in attempting by LANGER's method to develop those articular screw-models, found that when two casts were united, an apparently satisfactory helix was produced; but in adding to the series, the spire diminished, and the helix closed upon itself; so that it appeared that not only the angle of inclination of the thread, but also the radius of rotation, diminished. He was, therefore, of opinion, that the tibio-astragaloid articular surfaces could not be regarded as segments of a cylindrical series, and thought it extremely probable that, abstracting the terminal facets, the acting areas on each surface consist each of a segment of a conical screw—the convex portions of these two screws being on the astragaloid, the concave on the tibial articular surface; the one screw coming into action in flexion, the other in extension. GOODSIR's experiments on the knee and ankle-joints, conducted with extreme care, by the aid of fresh specimens, casts, and models, led him to conclude that both joints were 'spiral in their nature'—that in fact they were 'screwed structures,' and that the movements of the knee-joint are combined gliding and rolling movements of conical screwed surfaces upon one another. The following are his own words :—"The general character of the curves observed, and the corresponding movements and structure of the joint (knee-joint) leave little doubt in my mind that the flexion and extension, combined gliding and rolling movements of the knee, are performed between two conical double-threaded screw-combinations, an anterior and a posterior—the anterior being a left-handed screw, and the posterior

fish* as swimming in figure of 8, or looped curves. The wings of the insect, bat, and bird, are also described and figured as executing figure of 8 movements when the animals are hovering before an object, or when their bodies are artificially fixed (page 336, figure 2) ;† the figure of 8, as I explained, being opened out or unravelled when the animals are flying at a high horizontal speed to form a looped and then a waved track (pages 341, 342, 344, and 345, figures 10, 13, 14, and 15).‡

The following brief passages from my memoir in the Transactions of the Linnean Society§ will, I hope, serve to elucidate the peculiar figure of 8 movements made by the wings in flight :—

The Wing Twists and Untwists during its action.—"That the wing twists upon itself structurally, not only in the insect, but also in the bat and bird, any one may readily satisfy himself by a careful examination,‖ and that it twists upon itself during its action I have had the most convincing and repeated proofs.¶ The twisting in question is most marked in the posterior or thin margin of the wing, the anterior and thicker margin performing more the part of an axis. As a result of this arrangement, the anterior or thick margin cuts into the air quietly, and as it were by stealth, the posterior one producing on all occasions a violent commotion, especially perceptible if a flame be exposed behind the insect. Indeed, it is matter for surprise that the spiral conformation of the pinion, and its spiral mode of action, should have eluded observation so long ; and I shall be pardoned for dilating upon the subject when I state my conviction that it forms the fundamental and distinguishing feature in flight, and must be taken into account by all those who seek to solve this most involved and interesting problem by artificial means." The importance of the twisted configuration or screw-like form of the wing cannot be over-estimated. That this shape is intimately associated with flight is apparent from the fact that the rowing feathers of the wing of the bird are every one of them distinctly spiral in their nature ; in fact, one entire rowing feather is equivalent—morphologically and physiologically—to one entire insect wing. In the wing of the martin, where the bones of the pinion are short and in some respects rudimentary, the primary and secondary feathers are greatly developed, and banked up in such a

a right-handed screw in the right knee-joint ; the anterior a right-handed, and the posterior a left-handed screw in the left knee-joint. The movements which take place round these two combinations are alternate, those round the anterior completing extension and commencing flexion, those round the posterior completing flexion and commencing extension of the joint."

* *Op. cit.*, Diag. 2, page 204 ; Plate XV. fig. 76.
† *Op. cit.*, page 233, Diag. 5 ; Plate XV. fig. 61.
‡ *Op. cit.*, page 233, Diag. 6 ; Plate XV. fig. 59.
§ *Op. cit.*, pages 231, 232, 233, and 234.
‖ *Op. cit.*, Plate XV. figs. 68, 69, and 70.
¶ *Op. cit.*, Plate XV. figs. 58, 61, 73, and 74.

manner that the wing as a whole presents the same curves as those displayed by the insect's wing, or by the wing of the eagle where the bones, muscles, and feathers have attained a maximum development. The conformation of the wing is such that it presents a waved appearance in every direction—the waves running longitudinally, transversely, and obliquely. The greater portion of the pinion may consequently be removed without essentially altering either its form or its functions. This is proved by making sections in various directions, and by finding that in some instances as much as two-thirds of the wing may be lopped off without materially impairing the power of flight. Thus, in the summer of 1866,* I removed the posterior two-thirds from either wing of a blow-fly, and still the insect flew, and flew well. The only difference I could perceive amounted to this, that the fly, while it could elevate itself perfectly, flew in circles, and had less of a forward motion than before the mutilation. It had in fact lost propelling or driving power, the elevating or buoying power remaining the same. I took another blow-fly and removed the tip or outer-third of either wing, and found that the driving-power was the same as before the mutilation, while the elevating or buoying power was slightly diminished. These experiments prove that the posterior or thin elastic margin of the wing is more especially engaged in propelling, the tip in elevating.† "The spiral nature of the pinion is most readily recognised when the wing is seen from behind and from beneath,‡ and when it is foreshortened.§ It is also well marked in some of the long-winged oceanic birds when viewed from before,‖ and cannot escape detection under any circumstances, if sought for,—the wing being essentially composed of a congeries of curves, remarkable alike for their apparent simplicity and the subtlety of their detail."

The Wing during its action Reverses its Planes, and describes a Figure of 8 *track in space.*—"The twisting or rotating of the wing on its long axis is particularly observable during extension and flexion in the bat and bird, and likewise in the insect, especially the beetles, cockroaches, and others which fold their wings during repose. In these in extreme flexion the anterior or thick margin of the wing is directed downwards, and the posterior or thin one upwards. In the act of extension, however, the margins, in virtue of the wing rotating upon its long axis, reverse their positions, the anterior or thick margins describing a spiral course from below upwards, the posterior or thin margin describing a similar but opposite course from above downwards. These conditions, I need scarcely observe, are reversed during flexion. The movements of the margins during flexion and extension may be represented

* *Op. cit.*, pages 219, 220, 221, 222.
† For further experiments in this direction, see footnote to pages 361 and 362.
‡ *Op. cit.*, Plate XV. figs. 68, 69, 70, 73, and 74.
§ *Op. cit.*, Plate XV. figs 61 and 62.
‖ *Op. cit.*, page 253; Diagram 18 A, *a'b'*, *d'e'f.'*

with a considerable degree of accuracy by a figure of 8 laid horizontally.* . . . . It may likewise happen, though more rarely, that the anterior or thick margin of the pinion may be directed upwards and backwards during the return or up stroke. I infer this from having observed that the anterior margin of the wing of the wasp (when the insect is fixed and the wings are being driven briskly) is not unfrequently directed upwards and forwards at the beginning of the down stroke, and upwards and backwards at the commencement of the up or return stroke. A figure of 8, compressed laterally and placed obliquely with its long axis running from left to right of the spectator, represents the movement in question. The down and up strokes, as will be seen from this account, cross each other, the wing smiting the air during its descent from above, as in the bird and bat, and during its ascent from below, as in the flying fish and boys' kite. The pinion thus acts as a helix or screw in a more or less horizontal direction from behind forwards, and from before backwards; but it has a third function—it likewise acts as a screw in a nearly vertical direction from below upwards. . . . . If the wing (of the larger domestic fly) be viewed during its vibrations from above, it will be found that the blur or impression produced on the eye by its action is more or less concave. This is due to the fact that the wing is spiral in its nature,† and because during its action it twists upon itself in such a manner as to describe a double curve,‡—the one curve being directed upwards, the other downwards. The double curve referred to is particularly evident in the flight of birds from the greater size of their wings.§ The wing, both when at rest and in motion, may not inaptly be compared to the blade of an ordinary screw propellor as employed in navigation.‖ Thus the general outline of the wing corresponds closely with the outline of the propellor, and the track described by the wing in space is twisted upon itself propellor fashion. The great velocity with which the wing is driven converts the impression or blur¶ into what is equivalent to a solid for the time being, in the same way that the spokes of a wheel in violent motion, as is well understood, completely occupy the space contained within the rim or circumference of the wheel. . . . . From these remarks it will appear that not only the margins, but also the direction of the planes of the wing, are more or less completely reversed at each complete flexion and extension; and it is this reversing, or screwing and unscrewing, which enables the wing to lay hold of the air with such avidity during extension, and to disentangle itself with such facility during flexion,—to present, in fact, a more or less concave, oblique, and

* *Op. cit.*, page 233, Diagram 5. Compare this diagram with figs. 59 and 61 of Plate XV.
† *Op. cit.*, Plate XV. fig. 68.
‡ *Op. cit.*, Plate XV. figs. 58 and 59 *a a'*. Compare with *a a'* of fig. 52.
§ *Op. cit.*, Plate XV. figs. 73 and 75 *b a c*.
‖ *Op. cit.*, Plate XV. fig. 52 *a a'*.
¶ *Op. cit.*, Plate XV. figs. 58 and 59.

strongly resisting surface the one instant, and a comparatively narrow, non-resisting cutting edge the next. The figure of 8 action of the wing explains how an insect or bird may fix itself in the air, the backward and forward reciprocating action of the pinion affording support, but no propulsion. In these instances, the backward and forward strokes are made to counterbalance each other."

The Wing, when advancing with the body, Describes a Waved Track.—"Although the figure of 8 represents with considerable fidelity the twisting of the wing upon its axis during extension and flexion, when the insect is playing its wings before an object, or still better, when it is artificially fixed, it is otherwise when the down-stroke is added, and the insect is fairly on the wing, and progressing rapidly. In this case the wing, in virtue of its being carried forwards by the body in motion, describes an undulating or spiral course.* . . . . The down and up strokes are compound movements,—the termination of the down-stroke embracing the beginning of the up-stroke, the termination of the up-stroke, on the other hand, including the beginning of the down-stroke. This is necessary in order that the down and up strokes may glide into each other in such a manner as to prevent jerking and unnecessary retardation,—the angle made by the under surface of the wing with the horizon during the first part of the down-stroke being increased to support and propel the insect, and decreased during the second part to prepare it for making the up-stroke, and to diminish the friction caused by the wing itself, while it does not interfere with its sustaining power." . . . .

The Margins of the Wings thrown into Opposite Curves during Extension and Flexion.—"The anterior or thick margin of the wing and the posterior or thin margin present different degrees of curvature, so that under certain conditions the two margins cross each other, and form a true helix (page 361, fig. 37).† The anterior margin (*r*, *s*) presents two well-marked curves, a corresponding number being found on the posterior margin (*t*, *u*). These curves may, for the sake of clearness, be divided into axillary curves and distal curves, the former occurring towards the root of the wing, the latter towards its extremity. The curves (axillary and distal) found on the anterior margin of the wing are always the reverse of those met with on the posterior margin, *i.e.*, if the convexity of the anterior axillary curve be directed downwards (*r*),‡ that of the posterior axillary curve (*t*) is directed upwards,§ and so of the anterior and posterior distal curves (*s*, *u*). The two curves, axillary and distal, occurring on the anterior margin of the wing, are likewise antagonistic, the convexity of the axillary curve (*r*) being always directed downwards,‖ when the convexity of the

* *Op. cit.*, page 233, Diagram. 6.
† *Op. cit.*. Plate XV. figs. 70, 73, and 74.
‡ *Op. cit.*, Plate XV. fig. 73, *e*.
§ *Op. cit.*, Plate XV. fig. 73, *a*, *c*.
‖ *Op. cit.*, Plate XV. fig. 73, *c*.

distal one (*s*) is directed upwards,* and *vice versa*. The same holds true of the axillary and distal curves occurring on the posterior margin of the wing (*t. u*).† . . . . The anterior axillary and distal curves completely reverse themselves during the acts of extension and flexion, and so of the posterior axillary and distal curves. This reversal of the curves is seen to most advantage in the posterior margin of the wing, formed in the bird, by the primary, secondary, and tertiary feathers.‡ When the wing is partially flexed the convexity of the distal curve (occurring on the posterior margin of the wing) is directed downwards (page 362, figure 41 *a, b*),§ that of the axillary curve upwards (*a, c*).‖ When the wing is rather more than half extended the curves are obliterated, the posterior margin of the wing becoming straight (page 362, figure 42 *b, c*).¶ It is at this stage of extension that the axillary and distal curves reverse. When the wing is fully extended the convexity of the axillary curve is directed downwards (page 362, figure 43 *a, c*),** that of the distal one upwards (*a, b*),†† which is just the opposite of what happens in flexion. This antagonism in the axillary and distal curves observed in the posterior margin of the wing of the bird is referrible to changes induced in the anterior margin of the pinion, as the subjoined paragraph will show." . . . .

The Tip of the Bird's Wing describes an Ellipse.—"The movements of the wrist are always the reverse of those occurring at the elbow joint. Thus, during extension, the elbow and bones of the forearm are elevated, and describe one side of an ellipse; while the wrist and bones of the hand are depressed, and describe the side of another and opposite ellipse.‡‡ These movements are reversed during flexion,§§ so that when the elbow is raised and carried backwards, the wrist is lowered and carried forwards, and *vice versa*."‖‖ . . . .

The Wing capable of Change of Form in all its Parts.—"From this description it follows that when the different portions of the anterior margin are ele-

* *Op. cit.*, Plate XV. fig. 73, *f*.
† *Op. cit.*, Plate XV. fig. 73, *a, b, c*.
‡ *Op. cit.*, Plate XV. figs. 73, 74, 75.
§ *Op. cit.*, Plate XV. fig. 73, *b*.
‖ *Op. cit.*, Plate XV. fig. 73, *a, c*.
¶ *Op. cit.*, Plate XV. fig. 74, *b, c*.
** *Op. cit.*, Plate XV. fig. 75, *c*.
†† *Op. cit.*, Plate XV. fig. 75, *a, b*.
‡‡ *Op. cit.*, p. 249, Diagram 14.
§§ *Op. cit.*, p. 249, Diagram 15.

‖‖ Similar movements occur in the body and tail of the fish in the act of swimming. "The double curve or spiral into which the fish throws itself when swimming may be conveniently divided into an upper or cephalic curve,* and a lower or caudal one.† When the concavity of the caudal curve is biting or laying hold of the water, and when the concave surface of the tail is being forced during extension with great violence in the direction of the axis of motion,‡ where the concave surface is suddenly converted into a convex one, the concavity of the cephalic curve, *i.e.*, the concave surface of the upper half of the fish, is being urged, with less vigour, in the direction of the same line from the opposite side of it. As the caudal and cephalic curves are obliterated when the line in question is reached, there is, consequently, a period (momentary it must be), between the effective and non-effective strokes, in which the body of the fish is comparatively straight, and, consequently, in a position to advance almost without impediment."§

* *Op. cit.*, Diag. 2, *d*, p. 204. † *Op. cit.*, Diag. 2, *c*, p. 204. ‡ *Op. cit.*, Diag. 2, *a, b*, p. 204
§ *Op. cit.*, p. 205.

vated, corresponding portions of the posterior margin are depressed, the different parts of the wing moving in opposite directions, and playing, as it were, at cross purposes for a common good—the object being to rotate or screw the wing down upon the wind at a gradually increasing angle during extension, and to rotate it in an opposite direction and withdraw it at a gradually decreasing angle during flexion. It also happens that the axillary and distal curves co-ordinate each other and bite alternately, the distal curve posteriorly seizing the air in extreme extension with its concave surface (while the axillary curve relieves itself by presenting its convex surface), the axillary curve, on the other hand, biting during flexion with its concave surface (while the distal one relieves itself by presenting its convex one). The wing may, therefore, be regarded as exercising a fourfold function, the pinion in the bird being made to move from within outwards, and from above downwards during extension, in the effective or down stroke; and from without inwards, and from below upwards, during flexion in the up or return stroke."

The Wing during its Vibration produces a Cross Pulsation.—"This oscillation of the wing on two separate axes—the one running parallel with the body of the bird, the other at right angles to it—is well worthy of attention, as showing that the wing attacks the air on which it operates in every direction, and at almost the same moment, viz., from within outwards, and from above downwards, during the down or effective stroke; and from without inwards, and from below upwards, during the up or return stroke. As a corollary to the foregoing, the wing may be said to agitate the air in two principal directions, viz., from within outwards, or the reverse, and from behind forwards, or the reverse, the agitation in question producing two powerful pulsations—a longitudinal and a lateral; the longitudinal running in the direction of the *length* of the wing, the lateral in the direction of its *breadth*. As, however, the curves of the wing glide into each other when the wing is in motion, so the one pulsation merges into the other by a series of intermediate and lesser pulsations.

The longitudinal and lateral pulsations occasioned by the wing in action may be fitly represented by wave-tracks running at right angles to each other, the longitudinal wave track being the more distinct."

Analogy between the Wing in Motion and the Sounding of Sonorous Bodies.—"It is a remarkable circumstance that the undulation or wave made by the wing when the insect and bird are fixed or hovering before an object, and when they are progressing, corresponds in a marked manner with the track described by the stationary and progressive waves in fluids,* and likewise with the waves of sound.† This coincidence would seem to argue an intimate relation between

* Handbook of Natural Phil. (vol. on Electricity, Magnetism, and Acoustics), by Dr Lardner (Lond. 1863), pp. 366–7.

† *Op. cit.*, pp. 378, 379, 380.

the instrument and the medium on which it is destined to operate—the wing acting in those very curves into which the atmosphere is naturally thrown in the transmission of sound, in order, as appears to me, to secure the maximum of progression with the minimum of slip. Can it be that the animate and inanimate world reciprocate, and that animal bodies are made to impress the inanimate in precisely the same manner as the inanimate impress each other? This much seems certain :—The wind communicates to the water similar impulses to those communicated to it by the fish in swimming ; and the wing in its vibrations impinges upon the air as an ordinary sound would. The extremities of quadrupeds, moreover, describe spiral tracks on the land when walking and running ; so that one great law would seem to determine the course of the insect in the air, the fish in the water, and the quadruped on the land."

Various other passages might be adduced in elucidation and support of the curve, wave, or figure of 8 theory of flying, as originally propounded by me, but a sufficient number have, I trust, been cited to prove that the theory owes its origin and development to no hasty generalisation from a few scattered and imperfectly known facts, but that it rests upon a broad basis, such, in reality, as nature herself supplies.

In order that the reader may form his own conclusions on this point, I propose to lay before him in the course of my subsequent remarks the observations and experiments on which the theory was originally founded. The present memoir is illustrated by upwards of ninety original diagrams and drawings, the intricacy of the subject being such as to necessitate a free use of the pencil. The drawings have been made by myself from the life. I have gone into the origin and development of the figure of 8 theory of flying somewhat in detail ; first, because the passages selected have an obvious bearing on the subject of the present communication ; and second, because nearly two years after I had made my views known, Professor E. J. Marey (College of France, Paris), published a series of lectures and papers in the "Revue des Cours Scientifiques de la France et de L'Etranger,"* and in the "Comptes Rendus hebdomadaires des Séances de L'Académie des Sciences,"† in which the figure of 8 theory of wing movements is put forth as a new discovery. Professor Marey made no allusion to my researches, which was the more remarkable, as an abstract of my lecture, already referred to (p. 322), as published in the Proceedings of the Royal Institution of Great Britain in March 1867, was translated into French, and

* Les mouvements de l'aile chéz les insectes, p. 171, 13th Février 1869. Mécanisme du vol chez les insectes—comment se fait la propulsion, p. 252, 20th Mars 1869. Du vol des oiseaux, p. 578, 14 Aout 1869. Du vol des oiseaux (suite), p. 601, 21 Aout 1869. Du vol des oiseaux (suite), p. 646, 11 Septembre 1869. Du vol des oiseaux (fin), p. 700, 2 October 1869.

† Determination expérimentale du mouvement des ailes des insectes pendant le vol. Par M. E. J. Marey. Tome LXVII. p. 1341, Tome LXVIII. p. 667.

appeared on the 21st of September of that year in the same Journal* in which Professor MAREY's lectures were originally published. Having had my attention directed to this circumstance, I addressed a letter to the French Academy on the 28th of March 1870, which appeared in the "Comptes Rendus" (p. 875) on the 18th of April 1870. In it I claim to have been the first to describe and illustrate the following points, viz :—

That quadrupeds walk, and fishes swim, and insects, bats, and birds fly by figure of 8 movements.

That the flipper of the sea bear, the swimming wing of the penguin, and the wing of the insect, bat, and bird, are screws *structurally*, and resemble the blade of an ordinary screw propellor.

That those organs are screws *functionally*, from their twisting and untwisting, and from their rotating in the direction of their length, when they are made to oscillate.

That they have a reciprocating action, and reverse their planes more or less completely at every stroke.

That the wing describes *a figure of* 8 *track* in space when the flying animal is artificially fixed.

That the wing, when the flying animal is progressing at a high speed in a horizontal direction, describes *a looped* and then *a waved track*, from the fact that the figure of 8 is gradually opened out or unravelled as the animal advances.

That the wing acts after the manner of a kite.

Previous to replying to the foregoing, Professor MAREY wrote me, to inquire how he could respond to my "juste reclamation," without entering into a discussion which would needlessly complicate the question. I thereupon asked him to admit in a letter addressed to the French Academy my claim to have described and illustrated before him the figure of 8 movements made by the wings of insects, bats, and birds, when those animals are artificially fixed, and of the spiral and undulatory wave tracks made by the wings of said insects, bats, and birds, when the animals are flying at a high horizontal speed. This he has done, as the subjoined extract from his letter, printed in the "Comptes Rendus" for May 16, 1870 (p. 1093), will show :—"J'ai constaté qu' effectivement M. Pettigrew a vu avant moi, et représenté dans son Mémoire, la forme en 8 du parcours, de l'aile de l'insecte: que la méthode optique à laquelle j'avais recours est à peu près identique à la sienne . . . . je m' empresse de satisfaire à cette demande légitime, et je laisse entièrement la priorité sur moi, à M. Pettigrew relativement à la question ainsi restreinte."

Mode of Investigation pursued by the Author.—I obtained my results by

* Revue des Cours Scientifiques de la France et de l'Etranger.

transfixing the abdomen of insects with a fine needle, and watching the wings vibrate against a dark background; by causing dragon-flies, butterflies, blow-flies, wasps, bees, beetles, &c., to fly in a large bell jar, one side of which was turned to the light, the other side being rendered opaque by dark pigment; by throwing young pigeons and birds from the hand into the air for the first time; by repeated observation of the flight of tame and wild birds; by stiffening, by tying up, and by removing portions of the wings of insects and birds; by an analysis of the movements of the travelling surfaces of quadrupeds, amphibia, and fishes; by the application of artificial fins, flippers, tails, and wings to the water and air; and by repeated dissections of all the parts directly and indirectly connected with flight.

Professor MAREY obtained his results by gilding the extremities and margins of the wings of the insect with minute portions of gold leaf; by the application of the different parts (tip and anterior margin) of the wing of the insect to a smoked cylinder rotating at a given speed, the wing being made to record its own movements; by the captive and free flight of birds, which carried on and between their wings an apparatus which, by the aid of electricity, registered the movements of the wings on a smoked surface, travelling at a known speed in a horizontal direction; and by the employment of an artificial wing, constructed on the plan recommended by BORELLI, CHABRIER, STRAUS-DURCKHEIM, GIRARD, and others.

Professor MAREY describes and figures a captive insect (the wasp) with its wings forming figure of 8 loops,* and a free insect, with its wings describing a waved track,† precisely similar to what I described and figured in a variety of ways in my memoir.‡ He also shows that the tip of the wing of the bird, because of its alternately darting out and in during extension and flexion, describes an ellipse. This, curiously enough, is another of the many points in which I have anticipated this author, and one which I took special pains to establish,§ having in my memoir devoted no less than ten figures‖ to its illustration. Professor MAREY's views may therefore be regarded as confirmatory of my own, as the following brief passage, selected from one of his papers, will show. He writes:—"But if the frequency of the movements of the wing vary, the form does not. It is invariably the same—*it is always a double loop—a*

* Revue des Cours Scientifiques de la France et de l'Etranger, 13 Février 1869, page 175, figure 5. Professor MAREY represents the wing of the wasp as fanning the air in a vertical direction. In reality, the wing of the wasp and of most insects is made to vibrate very obliquely, and in a more or less horizontal direction.

† Revue des Cours Scientifiques et de la France et de l'Etranger, 13 Février 1869, pages 173, 174, and 176.

‡ Trans. Linn. Society, Vol. XXVI, page 233, Diagrams 5 and 6; page 249, Diagrams 14, 15, and 16; Plate XV. figures 59 and 61. *Vide* introduction to present memoir.

§ *Op. cit.*, pages 247, 248, 249, and 250.

‖ *Op. cit.*, pages 248 and 249, Diagrams 7, 8, 9, 10, 11, 12, 13, 14, 15, and 16.

figure of 8. Whether this figure be more or less apparent, whether its branches be more or less equal, matters little; it exists, and an attentive examination will not fail to reveal it."*

Professor MAREY'S experiments, I may add, have been repeated and verified in England by Mr SENECAL. This investigator also represents and describes the *double loop* and *figure of* 8 *movements*.† These two sets of experiments conducted independently, and after a considerable interval, by M. MAREY and Mr SENECAL respectively, will, I hope, suffice to establish the absolute correctness of the "Figure of 8 or Wave theory of Flight."

NATURAL FLIGHT.‡

Method of Testing the Accuracy of the Figure of 8 *Theory of Wing Movements.*—The correctness of the figure of 8 theory of flying may be readily established by a careful study of the rapidly vibrating wing of the wasp or common blow-fly.

If the body of the former be held, and the wing made to vibrate in front of a dark screen, it will be found that not only the tip but also the margins of the wing describe a figure of 8 track in space.

It will further be observed that the planes of the wing are as a rule reversed during the down and up strokes; nay, more, that the angles of inclination made by the surfaces of the wing with the horizon vary at every stage of the wing's progress, this variation in the angles being accompanied by a variation in the curves occurring on the anterior and posterior margins, as already explained. As a consequence, the wing is moving in all its parts at the same time—a somewhat remarkable occurrence, and calculated, it appears to me, to excite the curiosity, if it does not rivet the attention of physiologists. The wing of the insect is, with few exceptions, more flattened than that of the bat and bird, a circumstance which enables it, when it is made to vibrate in a more or less horizontal direction, and when its planes are reversed at the end of each stroke, to apply its under or ventral surface to the air when it is urged from behind forwards, and its upper or dorsal one when urged from before backwards (figures 3 and 4, page 338). It sometimes happens that the posterior margin of the wing is rotated in an upward direction at the end of the forward stroke, and in this case it is the under surface of the wing which is effective during the backward stroke (*vide g h i j k l* of figure 19, page 351).

* Méchanisme du vol des insectes—comment se fait la propulsion. Revue des Cours Scientifiques de la France et de l'Etranger, 20th March 1869.

† Fifth Annual Report of the Aëronautical Society of Great Britain for 1870, pages 42–47. Figures 1, 2; Diagrams 1–4.

‡ Artificial flight is described at page 402.

When the wing acts in this manner, it is the under or ventral surface which is effective both during the forward and backward strokes. The wing, during the back stroke occasions very little friction, from its being placed in a more or less horizontal position—this position being favourable to its affording a maximum of support. The upper and under surfaces of the wing are applied to the air alternately, more particularly when the insect is fixed, or when it is hovering in one spot. When it is flying at a high horizontal speed, and when the wing is made to oscillate in a slightly vertical direction, as in the butterfly (figures 29, 30, 31, 32, 33, and 34, page 360) and dragon-fly (figures 35, 36, 37, and 38, page 361), it is the under or concave surface of the pinion which does the principal part of the work, this attacking the air both during the down or forward stroke and the up or backward stroke, like a boy's kite, as explained at pages 349 and 350, figures 16 and 17. The direction of the stroke varies slightly according to circumstances, but it will be quite proper to assume that the wing of the insect is made to vibrate in a more or less *horizontal direction*, and that of the bird and bat in a more or less *vertical direction*. By a slight alteration in the position of the body, or by a rotation of the wing in the direction of its length, the vertical direction of the stroke is converted into a horizontal direction, and *vice versa*. The facility with which the direction of the stroke is changed is greatest in insects ; it is not uncommon to see them elevate themselves by a figure of 8 *horizontal* screwing motion, and then, suddenly changing the horizontal screwing into a more *vertical* one, to dart rapidly forward in a curved line. The horizontal screwing movement is represented at figures 2, 3, 4, 5, 6, 7, and 10, pages 336, 338, 340, and 341 ; and the vertical screwing at figures 12 and 13, page 342. The horizontal action of the insect's wing is described at pages from 336 to 341 inclusive, and the vertical action at pages from 347 to 355 inclusive. The vertical action of the bat and bird's wing is described at page 342, and at pages from 366 to 397 inclusive. Whether the wing is made to vibrate vertically or horizontally, it, practically speaking, in *progressive flight*, strikes *downwards and forwards* during the down stroke, and *upwards and forwards* during the up stroke, as fully explained at pages 344 and 345.

Compound Rotation of the Wing.—The wing during its vibration rotates upon two separate centres, the tip rotating around the root of the wing as an axis (short axis of wing), the posterior margin rotating around the anterior margin (long axis of wing). This compound rotation goes on throughout the entire down and up strokes, and is intimately associated with the power which the wing enjoys of alternately seizing and evading the air.

The Wing inclined Forwards at the End of the Down Stroke and Backwards at the End of the Up Stroke.—I had my attention first strongly directed to the screwing figure of 8 action of the wing by closely observing the twisting figure

of 8 movements made by the pectoral fins and tails of fishes, and from finding that in the beetle, blow-fly, and wasp (anterior wings), the posterior margin and body of the wing were inclined *forwards* (fig. 1 *a*) with reference to the head of the insect, at the end of the down stroke, and *backwards* (fig. 1 *b*) at the end of the up stroke.

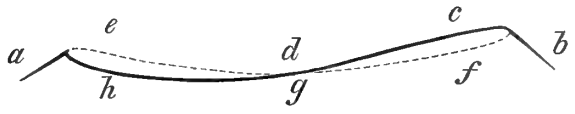


Fig. 1.

The Wing Rotates upon its Long Axis.—This at once suggested a rotation of the wing upon its long axis along its anterior margin, or, what is practically the same thing, a folding and plaiting of the posterior or thin yielding margin of the wing around the anterior semi-rigid and comparatively unyielding margin —a certain amount of rotation, or what is equivalent thereto, being necessary to reverse and change the planes of the wing at each stroke.

The Wing Twists and Untwists during its action.—I further observed that the planes of the wing were not only changed at the end of each stroke, but that the wing at this juncture was twisted upon itself, the outer portion of the posterior margin of the wing at the end of the down or forward stroke being inclined *forwards* (*g* of fig. 2), while the inner portion was inclined *backwards* (*r* of fig. 2); whereas at the termination of the up or backward stroke, the outer portion of the posterior margin was inclined *backwards* (*a* of fig. 2), while the inner portion was inclined *forwards* (*s* of fig. 2).

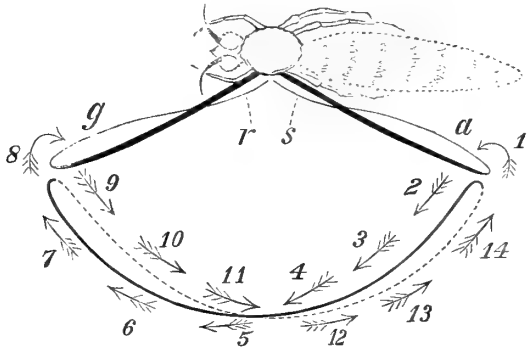


Fig. 2.

The Image produced on the Eye by the Wing in Motion is Concavo-Convex, and Twisted.—I likewise discovered that the blur or impression produced on the eye by the rapidly oscillating wing was *twisted upon itself* (fig. 1 *c d h, e g f*), and more or less *concave* above (*c d e* fig. 1), and *convex* below (*f g h* fig. 1), a circumstance which, while it strongly corroborated the opinion that the wing rotated upon its long axis during its vibration indicated that the twisting and reversal

of the planes of the wing occurred more especially at the end of the down and up strokes. I inferred this from observing that the angle made by the wing with the horizon is greater towards the termination than towards the middle of the strokes. This could readily be ascertained by looking at the blur produced by the oscillating wing edgewise, and this view revealed what is perhaps the most important feature in wing movements, viz., that the tip of the wing during its vibrations describes a scooped out (*c d e* fig. 1) figure of 8 track as represented at 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, and 14 of fig. 2.

The Direction of the Stroke of the Wing in the Insect—what Effective and what Non-effective—the Kite-like Action of the Wing.—This view also showed that the wing of the insect is made to vibrate in a more or less horizontal direction (figs. 3 and 5, page 338, Plate XI. fig. 4), in which respect it differs somewhat from the wing of the bat and bird, these being worked more or less vertically (Plate XI. figs. 5 and 6, and Plate XIV. figs. 18 and 19). The oblique action of the pinion is necessary to avoid the resistance of the air during the up stroke, the wing of the insect being in one piece, and having in many cases no adequate apparatus for diminishing its area during its ascent. One great advantage gained by the wing of the insect reversing its planes at the end of each stroke consists in the great length of the effective stroke—the wing flying backwards and forwards like a true kite, and tacking upon the air so suddenly as to occupy very little either of time or space.* The period occupied by the wing in reversing does not apparently amount to more than one-eighth of the time taken up by one entire stroke, so that something like seven-eighths of the area mapped out by the rapidly vibrating wing represents buoying area—the remaining eighth slip. This, put in other words, simply means that in one passage of the wing from behind forwards (down stroke) the pinion is effective in seven-eighths of its course and non-effective in one-eighth, the same remark being applicable to the passage of the wing from before backwards (up stroke).

The Wing Attacks the Air at various Angles.—It is just possible that even less than one-eighth is devoted to slip, from the fact that the wing when it is being reversed is slowed and applied to the air at an increased angle—a surface which makes a large angle with the horizon, giving, when forced against the air at a low speed, as much support as a similar surface whose inclination is less, but whose speed is higher. As the wing attacks the air during the down and up strokes at various angles, those angles being greatest when the wing travels slowest, and least when the wing travels most rapidly, it follows that the wing adapts itself to the resistance opposed to its passage by the air, and always extracts the maximum of support from it. The wing, in this respect, differs

* The movements of the wing somewhat resemble those of a sailing ship. The wing and ship both tack upon the wind, and both change their tack or reverse abruptly. The changing of the tack is moreover always accompanied by a slowing or diminution of the speed.

widely from the screw propellors at present in use—the blades of these propellors always striking at a given angle and in the same direction. The advantage in favour of the wing as compared with the screw as employed in navigation is very great, and not at present understood.* The area mapped out by the wing during the effective stroke and while reversing; the various angles made by the surfaces of the wing with the horizon in its passage to and fro; the rotating and twisting of the posterior or thin margin of the wing round the anterior or thick margin; and the figure of 8 track made by the tip of the wing during its action, as seen in the wasp, are shown at figs. 3, 4, 5, and 6.

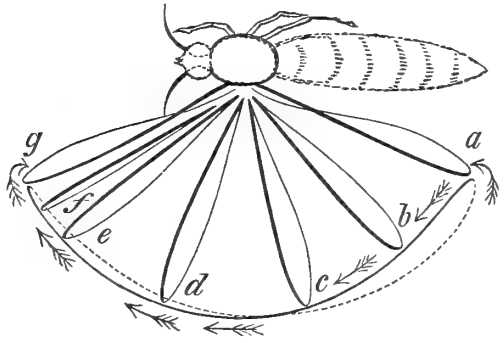


Fig. 3.

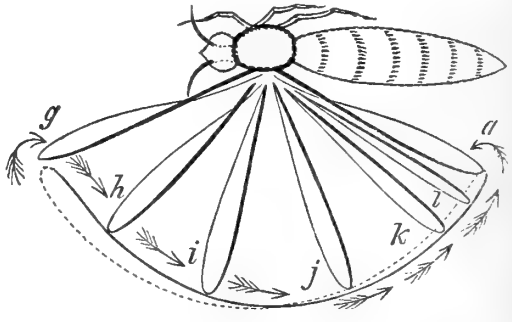


Fig. 4.

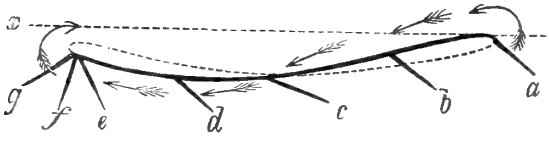


Fig. 5.

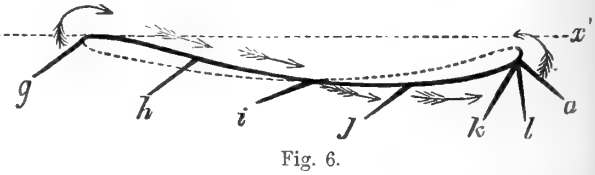


Fig. 6.

Analysis of the Movements of the Wing of the Wasp, Reversal of the Planes of the Wing, Reciprocating Action, &c.—In the wasp the wing commences the down or forward stroke at *a* of figures 3 and 5; and it will be observed that the angle which it makes with the horizon (*x* of fig. 5) is something like 45°. At *b* (figures 3 and 5) the angle is slightly diminished, partly because of a rotation of the wing along its anterior margin (long axis of wing), partly from increased speed, and partly from the posterior margin of the wing yielding to a greater or less extent.

At *c* the angle is still more diminished from the same causes.

At *d* the wing is slowed slightly, preparatory to reversing, and the angle made with the horizon (*x*) increased.

At *e* the angle, for the same reason, is still more increased; while at *f* the wing is at right angles with the horizon. It is, in fact, in the act of reversing.

* For specific differences between the screws formed by the wings and the propellors employed in navigation, see memoir by the author, Trans. Linn. Society, vol. xxvi. pages 228, 229, 230, and 231.

At *g* the wing is reversed, and the up or back stroke commenced.

The angle made at *g* is, consequently, the same as that made at *a* (45°), with this difference, that the anterior margin and outer portion of the wing, instead of being directed *forwards,* with reference to the head of the insect, are now directed *backwards.*

During the up or backward stroke all the phenomena are reversed, as shown at *g h i j k l* of figures 4 and 6 ; the only difference being that the angles made by the wing with the horizon are somewhat less than during the down or forward stroke—a circumstance which facilitates the forward travel of the body, while it enables the wing during the back stroke still to afford a considerable amount of support. This arrangement permits the wing to travel backwards when the body is travelling forwards ; the diminution of the angles made by the wing in the back stroke giving very much the same result as if the wing were striking in the direction of the travel of the body. The slight upward inclination of the wing during the back stroke permits the body to fall downwards and forwards to a slight extent at this peculiar juncture, the fall of the body, as will be more fully explained hereafter, contributing to the elevation of the wing.

If figure 5, representing the down or forward stroke, be placed upon figure 6, representing the up or backward stroke, it will be seen that the wing crosses its own track more or less completely at every stage of the down and up strokes. As, moreover, the wing draws a current after it, and is pursued in its passage from above downwards by a stream of air which it meets in its passage from below upwards, it follows that the pinion, during the down or *forward stroke,* creates a current on which it operates during the up or *backward stroke,* and *vice versa;* hence the *reciprocating action* of the wing.

The wing reciprocates most perfectly, and the figure of 8 is most distinct when the insect is fixed artificially, or when it is hovering of its own accord in a given spot, as is well shown at *a b c d e f g h i j k l m n o p* of fig. 8, p. 340, where the wing is represented as screwing steadily downwards.

Points wherein the Wing differs from the Scull of the Boatman.—The downward screwing movement of the wing somewhat resembles the action of an oar in sculling, as represented at *a b, c d, x s,* of fig. 7, the cross movement occasioned by the rotation of the wing on its long axis as it darts to and fro being shown at *m n, o p, q r.* There is, however, this marked difference. It is the *upper* surface of the oar which is effective in sculling, whereas it is the *under* surface of the wing which is effective in flying.* This is accounted for by the fact that the oar simply propels —the boat being buoyant, the wing propelling and

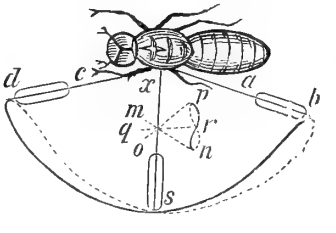


Fig. 7.

* A precisely similar difference is found to exist between the aërial or flying wing and the subaquatic

likewise elevating. There is this further difference. The margins of the blades of the oar are of the same thickness, the axis of rotation running midway between the two ; the anterior margin of the wing, on the contrary, is much thicker than the posterior one, the axis of rotation corresponding to the former. The oar, as far as the margins of its blade are concerned, is as it were *concentric*, the wing *eccentric*. As the downward screwing movement of the wing, in virtue of the action and reaction of the wing and air upon each other, is at once converted into an upward screwing movement, as shown at *a′ b′ c′ d′ e′ f′ g′ h′ i′ j′ k′ l′ m′ n′ o′ p′* of fig. 9, it follows that the body of the insect is rapidly but steadily elevated in an almost vertical wave-line. The impulse is communicated to the wing at points corresponding to the heavy portions of the line in figure 8, and the corresponding upward recoil is indicated at similar points in figure 9.

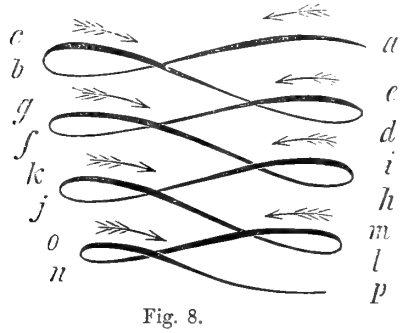


Fig. 8.

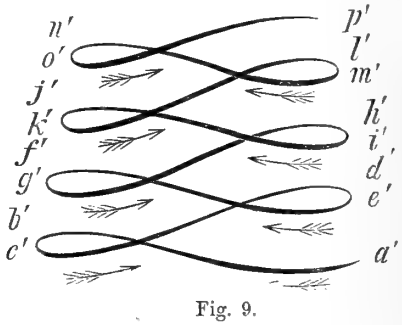


Fig. 9.

How the Figure of 8 *is Unravelled, and becomes a Waved-Track.*—When the insect flies in a horizontal direction, and the speed attained increases with the duration of flight, the wing reciprocates less and less perfectly, because the figure of 8 sweeps described by it are converted into a looped and then a waved track, as represented at *a b c d e f g h i j k l m n o p q r s t* of figure 10 (p. 341); the corresponding looped and waved track due to recoil being shown at similar letters of figure 11 (p. 341). When the horizontal speed attained by the insect is high,

or diving wing. In the gannet, cormorant, merganser, grebe, &c., which fly under the water, it is the upper or dorsal surface of the pinion which gives the effective stroke, whereas in aërial flight it is the under or ventral surface. This is proved by the fact that in the penguin and great auk, which are incapable of flying out of the water, and confine their efforts to diving or swimming under it, the wing is actually twisted round, so that the dorsal surface of the pinion occupies the position normally occupied by the ventral surfaces in all other birds. This is necessitated by the fact that a diving bird, seeing it is of lighter specific gravity than the water, must always fly downwards ; in other words, it must counteract buoyancy as the flying bird counteracts gravity—buoyancy forcing the diving bird to the surface of the water in the same way that gravity drags the flying bird to the surface of the earth. Levity and weight are therefore separate forces, and act under diametrically opposite conditions, levity being quite as useful to the diving bird as weight to the flying one. The wings of diving birds are applied to the water precisely in the same manner as the flippers of the seal, sea bear, walrus, turtle, porpoise, whale, manatee, &c. All these animals are lighter than the water, and, as a consequence, their travelling surfaces to be effective must act *from below* as in the case of the scull. It is the reverse in the air, the travelling surfaces acting invariably *from above*. For further development of this view see footnote to page 371.

the wing is successively and rapidly brought into contact with innumerable columns of undisturbed air. It consequently is a matter of indifference whether the wing is carried at a high speed against undisturbed air, or whether it operates upon air travelling at a high speed (as, *e.g.*, the artificial currents produced by the rapidly reciprocating action of the wing). The result is the same in both cases, inasmuch as a certain quantity of air is worked up under the wing, and the necessary degree of support and progression extracted from it. It is, therefore, quite correct to state, that as the horizontal speed of the body increases the reciprocating action of the wing decreases, and *vice versa*. In fact, the reciprocating and non-reciprocating function of the wing in such cases is purely a matter of speed. If the travel of the wing is greater than the horizontal travel of the body, then the figure of 8 and the reciprocating power of the wing will be more or less perfectly developed, according to circumstances. If, however, the horizontal travel of the body is greater than that of the wing, then it follows that no figure of 8 will be described by the wing, that the wing will not reciprocate to any marked extent, and that the organ will describe

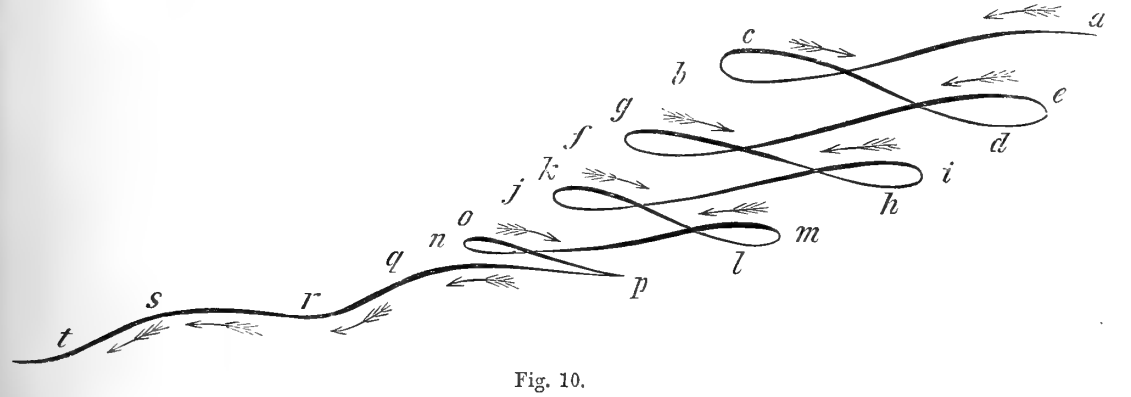


Fig. 10.

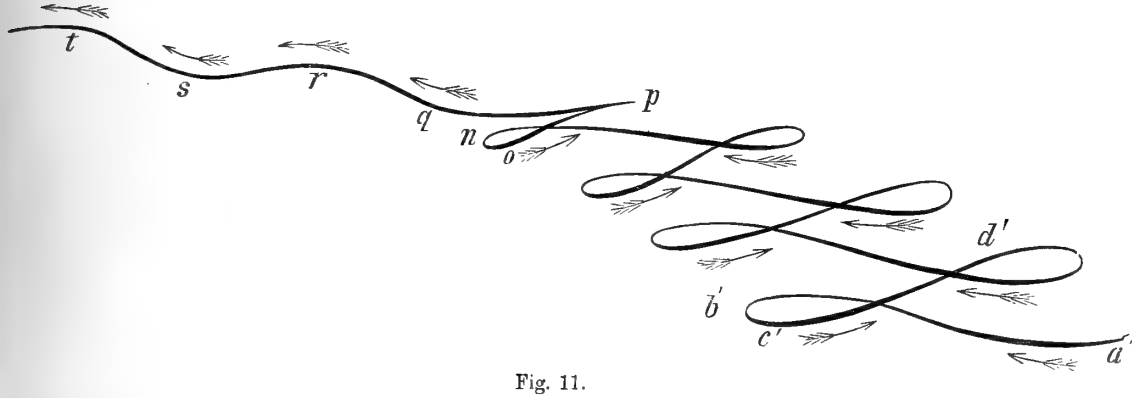


Fig. 11.

a waved track, the curves of which will become less and less abrupt, *i.e.*, longer and longer in proportion to the speed attained. The downward looped track represented at fig. 10, is at once converted into an upward looped track, as shown at figure 11, in virtue of the action and reaction of the wing and air upon each

other, the body of the insect being carried along a waved line obliquely upwards and forwards (*q r s t*, fig. 11, p. 341). The waved track made by the wing is generated by the figure of 8 loops being gradually opened out, these becoming less and less distinct as the insect advances, as is more especially shown at *n o p q r s t* of both figures (10 and 11, p. 341). The impulse is communicated to the wing at *a c e g i k m o q s* of fig. 10, and the upward recoil at corresponding letters of fig. 11.

The waved track formed by the ascent and descent of the wing of the bat and bird is originated in a similar manner, but in this case the figure of 8 loops are disposed more vertically, because of the more vertical direction of the stroke, as shown at *e f g h i j k l* of figure 12. (*Vide* also Plate XI. figures 5 and 6). In this figure (12) the oar, as seen at *a b*, *x s*, and *c d*, represents the

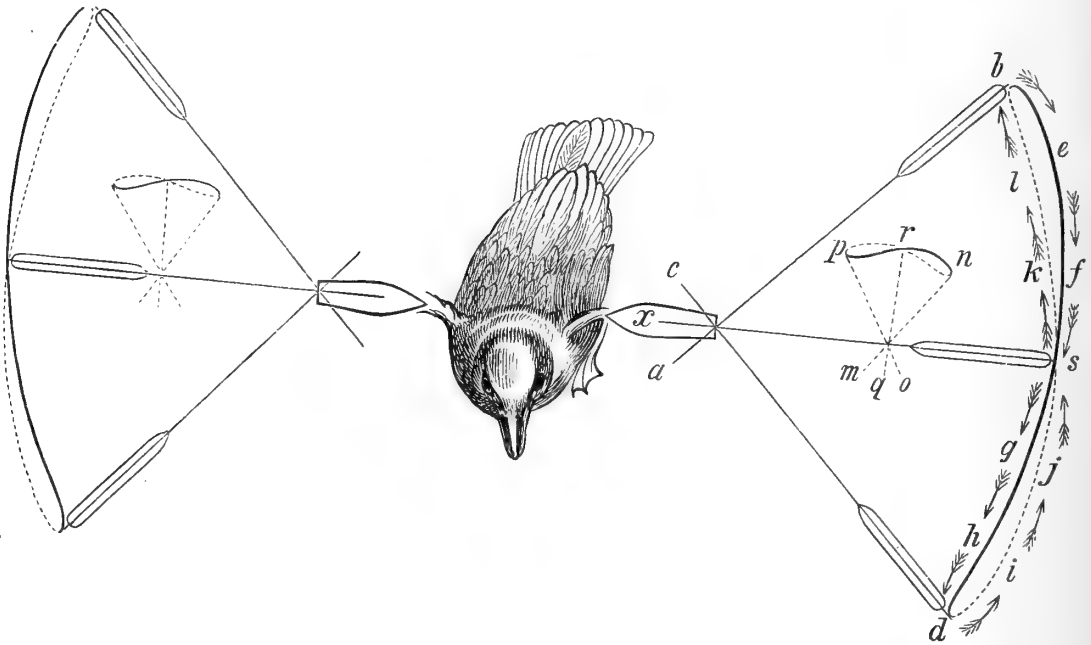


Fig. 12.

wing of the bat and bird at the beginning, middle, and termination of the down stroke—the little oar, *m n o p q r*, indicating the cross action of the wing. The large oar is more especially engaged in elevating, the little one in propelling. The manner in which the figure of 8 loops made by the wing of the bat and bird during its ascent and descent are opened out or unravelled by the

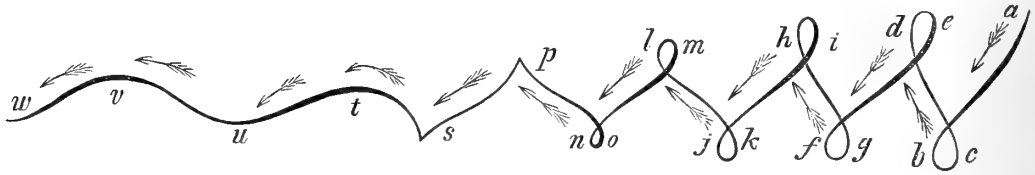


Fig. 13.

horizontal travel of the body is shown at *a b c d e f g h i j k l m n o p* of figure 13; the completed waved track being seen at *s t u v w* of the same figure.

When the Wing Ascends the Body Descends, and vice versa.—As the body of the insect, bat, and bird falls forwards in a curve when the wing ascends, and is elevated in a curve when the wing descends, it follows that the trunk of the animal is urged along a waved line, as represented at 1, 2, 3, 4, 5 of figure 14, p. 344, the waved line *a c e g i* of the same figure giving the track made by the wing. I have distinctly seen the alternate rise and fall of the body and wing when watching the flight of the gull from the stern of a steam-boat.

The direction of the stroke in the insect (figs. 3, 5, and 8, pp. 338, 340), as I have already explained, is much more horizontal than in the bat or bird (figs. 12 and 13, p. 342). In either case, however, the down stroke must be delivered in a more or less forward direction. This is necessary for support and propulsion. A horizontal to and fro movement will elevate, and an up and down vertical movement propel, but an oblique forward motion is requisite for progressive upward flight.*

The Wing during its Vibrations moves on the Surface of an Imaginary Sphere.—All wings are convex above and concave below. This shape is necessary to enable the wing to evade the air during the up stroke, and to seize it during the down one. The concave surface is presented during the up stroke, and the concave one during the down stroke—the resistance experienced by a concave surface when compared with a convex one being something like two to one. The resistance is further increased by the wing being made to descend with greater rapidity than it ascends. In whatever direction the wing turns during the up stroke its movements are calculated to evade the air, and in whatever direction it turns during the down stroke they are calculated to seize it. This arises alike from the shape of the wing and the manner in which it is applied to the air. Thus, in the insect in progressive flight the wing during the up stroke describes a curve which is directed upwards and forwards. In the bat and bird, where the wing is drawn towards the body during the up stroke, the wing describes a second curve, this curve being directed upwards and inwards with reference to the body. The under or concave surface of the wing may, therefore, be said to be moving on the surface of an imaginary sphere during the up stroke—an arrangement which enables it to avoid the superincumbent air by its upper or convex surface, while it affords a certain amount of support and ascensional power by its under or concave surface, this latter acting partly as a kite and partly as a parachute. The wing may, in fact, be said to climb during the up stroke ; and this climbing is so adroitly performed that two objects are served by it—the superimposed air being avoided, and the body bearing the wing being supported. In the climbing movement the anterior margin of the wing cleaves a passage from behind upwards and forwards for the body

* On the Mechanism of Flight, by the Author, Trans. Linn. Society, vol. xxvi. pages 214, 255, and 256.

and posterior margin, the root in like manner cleaving a passage from without inwards and upwards for the body and tip. It is in this way that the wing presents a sharp cutting edge during the up stroke, a remark which applies even to the rowing feathers (quill feathers) of the wing of the bird. The ascent of the wing, as will be subsequently explained, is favoured by the reaction of the air on its under surface, and by the downward and forward fall of the body. If the wing was not concavo-convex in form, and made to oscillate on the surface of an imaginary sphere, it would be impossible for it alternately to avoid and seize the air while it is rising and falling. When the wing descends or makes the down stroke, as it is termed, it also rotates on the surface of the imaginary sphere in question. In this case, however, it is the concave or under surface of the wing which is active, and the rolling takes place in such a manner (it is outwards, downwards, and forwards) as actually greatly to increase the support afforded—the air, which was dispersed and avoided during the up stroke, being now collected together and seized with avidity. It would be difficult to conceive a more simple or effective arrangement.

The Natural Wing, when Elevated and Depressed, must move Forwards.—It is a condition of natural wings, and of artificial wings constructed on the principle of living wings, that when forcibly elevated or depressed, even in a strictly vertical direction, they inevitably dart forward. This is well shown in figure 14.

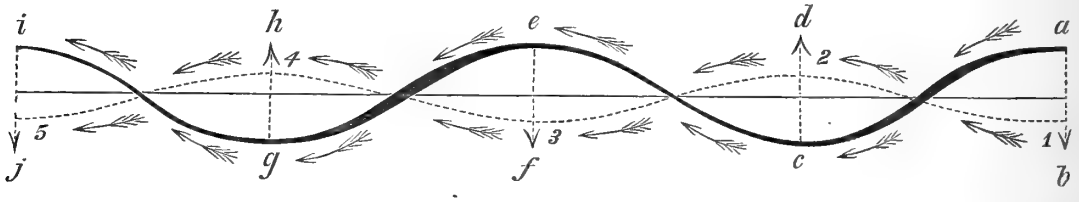


Fig. 14.

If, for example, the wing is suddenly depressed in *a vertical direction,* as represented at *a b,* it at once darts downwards and forwards in a curve to *c,* thus converting the vertical down stroke into *a down oblique forward stroke.* If, again, the wing be suddenly elevated in a strictly vertical direction, as at *c d,* the wing as certainly darts upwards and forwards in a curve to *e,* thus converting the vertical up stroke into an *upward oblique forward stroke.* The same thing happens when the wing is depressed from *e* to *f,* and elevated from *g* to *h.* In both cases the wing describes a waved track, as shown at *e g, g i,* which clearly shows that the wing strikes *downwards and forwards* during the down stroke, and *upwards and forwards* during the up stroke. The wing, in fact, is always advancing, its under surface attacking the air like a boy's kite. If, on the other hand, the wing be forcibly depressed, as indicated by the heavy waved line *a c,* and left to itself, it will as surely rise again, and describe a waved track, as shown at *c e.* This it does, in virtue of its flexibility and elasticity,

aided by the recoil obtained from the air. In other words, it is not necessary to elevate the wing forcibly in the direction *c d* to obtain the upward and forward movement *c e*. One single impulse communicated at *a*, causes the wing to travel to *e*, and a second impulse communicated at *e*, causes it to travel to *i*. It follows from this that a series of vigorous down impulses would, *if a certain interval was allowed to elapse between them*, beget a corresponding series of up impulses, in accordance with the law of action and reaction, the wing and the air under these circumstances being alternately active and passive. I say if a certain interval was allowed to elapse between every two down strokes, but this is practically impossible, as the wing is driven with such velocity that there is positively no time to waste in waiting for the purely mechanical ascent of the wing. That the ascent of the pinion is not, and ought not to be, entirely due to the reaction of the air, is proved by the fact that in flying creatures (certainly in the bat and bird) there are distinct elevator muscles and elastic ligaments, delegated to the performance of this function. The reaction of the air is therefore only one of the forces employed in elevating the wing; the others, as I shall show presently, are vital and vito mechanical in their nature. The falling downwards and forwards of the body when the wings are ascending also contribute to this result.

The Wing acts as a true Kite both during the Down and Up Strokes.—If, as I have endeavoured to explain, the wing, even when elevated and depressed in a strictly vertical direction, inevitably and invariably darts forward (figure 14, p. 344), it follows as a consequence that the wing, as already partly explained, flies forwards as a true kite, both during the down and up strokes, as shown at *c d e f g h i j k l m* of fig. 15, and that its under concave or biting surface, in virtue of the forward travel communicated to it by the body in motion, is closely applied to the air, both during its ascent and descent, a fact hitherto overlooked, but one of considerable importance, as showing how the wing furnishes a persistent buoyancy, alike when it rises and falls.

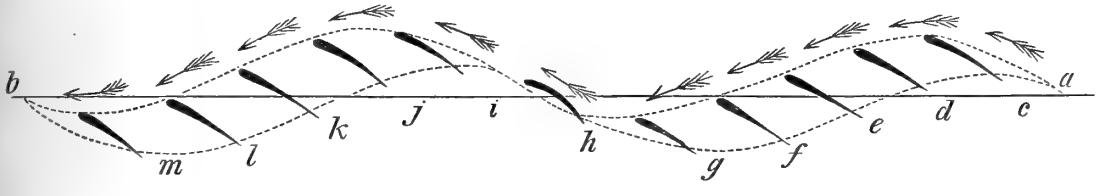


Fig. 15.

In figure 15 the greater impulse communicated during the down stroke is indicated by the double dotted lines. The angle made by the wing of the bat and bird with the horizon (*a b* of figure 15) is constantly varying, as in the insect wing, as a comparison of *c* with *d*, *d* with *e*, *e* with *f*, and *f* with *g* of figure 15 will show, these letters having reference to supposed transverse sections of the

wing. Figure 15 also shows that the *convex* or non-biting surface of the wing is always directed upwards, so as to avoid unnecessary resistance on the part of the air to the wing during its ascent, whereas the *concave* or biting surface is always directed downwards, so as to enable the wing to contend successfully with gravity.

On comparing *c d e f g* of figure 15, p. 345, with *a b c d* of figures 3 and 5, p. 338, it will be seen that the principle involved in the flight of the wing of the insect, bat, and bird is essentially the same. The wing is, in short, in every instance, a true kite, and flies forward in accordance with natural laws.

Where the Kite formed by the Wing differs from the Boy's Kite.—The natural kite formed by the wing differs from the artificial kite only in this, that the former is capable of being moved in all its parts, and is more or less flexible and elastic, the latter being comparatively rigid. The flexibility and elasticity of the kite formed by the natural wing is rendered necessary by the fact that the wing is articulated or hinged at its root; its different parts travelling at various degrees of speed in proportion as they are removed from the axis of rotation. Thus the tip of the wing travels through a much greater space in a given time than a portion nearer the root. If the wing was not flexible and elastic, it would be impossible to reverse it at the end of the up and down strokes, so as to produce a continuous vibration. The wing is also practically hinged along its anterior margin, so that the posterior margin of the wing travels through a much greater space in a given time than a portion nearer the anterior margin. The compound rotation of the wing is greatly facilitated by the flexible and elastic properties of the pinion. It causes the pinion to twist upon its long axis during its vibration, as already fully explained (see *g, r* and *a, s* of fig. 2, p. 336). The twisting referred to is partly a vital and partly a mechanical act; that is, it is occasioned in part by the action of the muscles, and in part by the greater momentum acquired by the tip and posterior margin of the wing, as compared with the root and anterior margin; the speed acquired by the tip and posterior margin causing them to reverse always subsequently to the root and anterior margin, which has the effect of throwing the anterior and posterior margins of the wing into figure of 8 curves. It is in this way that the posterior margin of the outer portion of the wing is made to incline forwards at the end of the down stroke (fig. 2 *g*, p. 336), when the anterior margin is inclined backwards, and that the posterior margin of the outer portion of the wing is made to incline backwards at the end of the up stroke (fig. 2 *a*, p. 336), when a corresponding portion of the anterior margin is inclined forwards.

The Angles formed by the Wing in Action.—Not the least interesting feature of the compound rotation of the wing, of the varying degrees of speed attained by its different parts, and of the twisting or plaiting of the posterior margin around the anterior, is the great variety of kite-like surfaces developed upon

its dorsal and ventral aspects. Thus the tip of the wing forms a kite which is inclined upwards, forwards, and outwards, while the root forms a kite which is inclined upwards, forwards, and inwards. The angles made by the tip and outer portions of the wing with the horizon are less than those made by the body, and those made by the body less than those made by the root and inner portions. The inclined surfaces peculiar to any portion of the wing become more inclined as the speed peculiar to said portion decreases, and *vice versa*. The wing is consequently mechanically perfect, the angles made by its several parts with the horizon being accurately adjusted to the speed attained by its different portions during its travel to and fro. From this it follows that the air set in motion by one part of the wing is seized upon and utilised by another, the inner and anterior portions of the wing supplying, as it were, currents for the outer and posterior portions. This results from the wing always forcing the air outwards and backwards. These statements admit of direct proof, and I have frequently satisfied myself of their exactitude by experiments made with natural and artificial wings.

In the bat and bird the twisting of the wing upon its long axis is more of a vital and less of a mechanical act than in the insect, the muscles which regulate the vibration of the pinion in the former (bat and bird), extending quite to the tip of the wing.

The Body and Wings move in Opposite Curves.—I have stated that the wing advances in a waved line, as shown at *a c e g i* of figure 14, p. 344; and the same remark holds true, within certain limits, of the body as indicated at 1, 2, 3, 4, and 5 of the same figure. Thus, when the wing descends in the curved line *a c*, it elevates the body in a corresponding but minor curved line, as shown at 1, 2; when, on the other hand, the wing ascends in the curved line *c e*, the body descends in a corresponding but smaller curved line (2, 3), and so on *ad infinitum*. The undulations made by the body are so trifling when compared with those made by the wing that they are apt to be overlooked. They are, however, deserving of attention, as they exercise an important influence on the undulations made by the wing, the body and wing swinging forward alternately, the one rising when the other is falling, and *vice versa*. Flight may be regarded as the resultant of three forces:—the *muscular and elastic force*, residing in the wing, which causes the pinion to act as a true kite, both during the down and up strokes; the *weight of the body*, which becomes a force the instant the trunk is lifted from the ground, from its tendency to fall downwards and forwards; and *the recoil obtained from the air* by the rapid action of the wing. These three forces may be said to be active and passive by turns.

Analysis of the Down and Up Strokes in the Insect—the Terms Extension and Flexion defined.—As considerable confusion exists in the minds of most investigators as to the precise changes induced in the wing during the *down* and *up*

strokes respectively, and in especial as to the manner in which the wing is elevated, so as to avoid the resistance of the air and yet afford support, I have felt it incumbent upon me carefully to analyse the movements as observed in progressive flight. In insects the wings are variously arranged during the period of repose. In some they are elevated above the body, as in the butterfly; in others, they are disposed on the same level with the body, and rest upon the dorsal surface of the abdomen, as in the common fly; in a third, the wings are arranged partly on the sides and partly upon the dorsal aspect of the body, the anterior or thick margin of the wing being in such cases directed downwards, as in the cicada. This is also the position occupied by the wings of the bat and bird, the pinions, when not employed in flying, being folded upon themselves to economise space. In some insects, as the ephemera or mayfly, the beetles, locusts, &c., the wings are also folded upon themselves during the intervals of rest. The power which some wings possess of alternately folding, flexing, or crushing their component parts together, and of extending and widely separating them, has introduced the terms *extension* and *flexion*: extension, strictly speaking, signifying the opening out or spreading of the pinion, and the carrying of it away from the body in the direction of the head of the animal; flexion signifying the folding of the pinion, and the drawing of it towards the body in a direction from before backwards. The terms extension and flexion, when applied to insect wings, which are in one piece, and which consequently do not admit of being alternately opened and closed to any great extent, are only partly correct,—extension in the insect, signifying the carrying of the wing away from the body in a plane nearly on the same level with it in the direction of the head; flexion the drawing back or recovering of the wing until it regains its original position.

The terms extension and flexion have, unfortunately, got mixed up with the expressions the *down* and *up* strokes, from the fact that the wings of bats, birds, and some insects are always extended towards the termination of the up strokes, and flexed towards the termination of the down ones. This confusion is the more natural as all wings when extended rotate upon their long axes in such a manner that their posterior margins are screwed *downwards* and *forwards*.

In all wings, whatever their position during the intervals of rest, and whether in one piece or in many, this feature is to be observed in flight. The wings are slewed downwards and forwards, *i.e.*, they are carried more or less in the direction of the head during their descent, and reversed or carried in an opposite direction during their ascent. In stating that the wings are carried away from the head during the back stroke, I wish it to be understood that they do not therefore necessarily travel backwards in space when the insect is flying forwards. On the contrary, the wings, as a rule, move forward in curves, both during the down and up strokes. The fact is, that the wings at their roots are

hinged and geared to the body so loosely that the body is free to oscillate in a forward or backward direction, or in an up, down, or oblique direction. As a consequence of this freedom of movement, and as a consequence likewise of the speed at which the insect is travelling, the wings during the back stroke are for the most part actually travelling forwards. This is accounted for by the fact that the body falls downwards and forwards in a curve during the up or return stroke of the wings, and because the horizontal speed attained by the body is as a rule so much greater than that attained by the wings, that the latter are never allowed time to travel backward, the lesser movement being as it were swallowed up by the greater. For a similar reason the passenger of a steam-ship may travel rapidly in the direction of the stern of the vessel, and yet be carried forward in space,—the ship sailing much quicker than he can walk. While the wing is descending, it is rotating upon its root as a centre (short axis). It is also, and this is a most important point, rotating upon its anterior margin (long axis), in such a manner as to cause the several parts of the wing to assume various angles of inclination with the horizon.

Figures 16 and 17 will supply the necessary illustration.

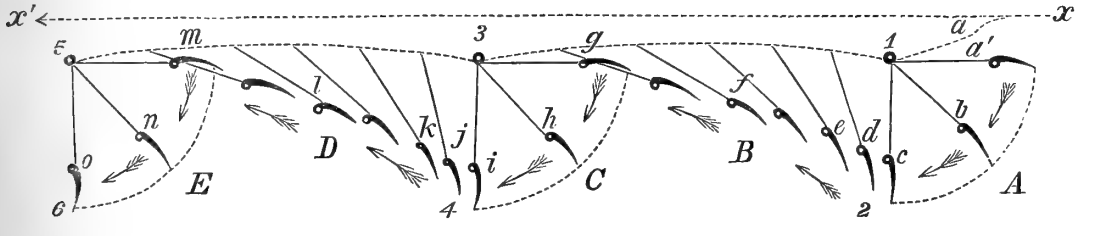


Fig. 16.

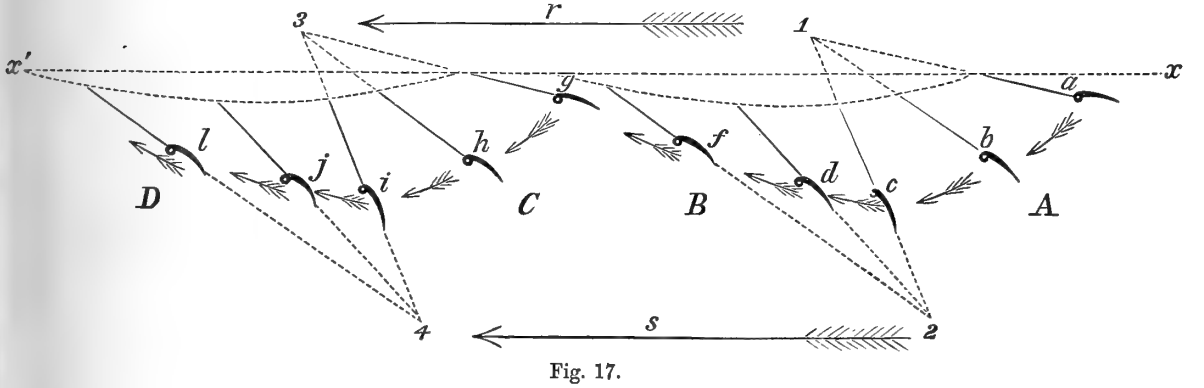


Fig. 17.

If, for example, we take the common blow-fly when reposing we will find that the plane of the wing (fig. 16 a') is arranged in the same plane with the body, and that both are in a line with the horizon ($x\,x'$).* When, however, the

* It happens occasionally in insects that the posterior margin of the wing is on a higher level than the anterior one towards the termination of the up stroke as shown at a (dotted line) of fig. 16. In such cases the posterior margin is suddenly rotated in a downward and forward direction at the

wing is made to descend, it gradually, in virtue of its simultaneously rotating upon its long and short axes, makes a certain angle with the horizon as represented at *b*. The angle is increased at the termination of the down stroke as shown at *c*, so that the wing, particularly its posterior margin, during its descent (*A*), is screwed or crushed down upon the air with its concavity or biting surface directed forwards and towards the earth. The same phenomena are indicated at *a b c* of fig. 17, p. 349, but in this figure the wing is represented as travelling more decidedly forwards during its descent, and this is characteristic of the down stroke of the insect's wing—the stroke in the insect being delivered in a very oblique and more or less horizontal direction, as shown at Plate XI. fig. 4. The forward travel of the wing during its descent has the effect of diminishing the angles made by the under surface of the wing with the horizon. Compare *b c d* of fig. 17 with the same letters of fig. 16. At fig. 15, page 345, the angles for a similar reason are still further diminished, and this latter figure gives a very accurate idea of the kite-like action of the wing both during its descent and ascent. The downward screwing of the posterior margin of the wing during the down stroke is well seen in the dragon-fly at page 361, fig. 38. (In this figure the arrows *r s* give the range of the wing.) At the beginning of the down stroke (dragon-fly) the upper or dorsal surface of the wing (*i d f*) is inclined *downwards and backwards*, the under or ventral surface *downwards and forwards*. In other words, the anterior margin (*i d*) of the pinion is directed slightly upwards and forwards, the posterior margin (*f*) slightly downwards and backwards. As the wing descends, which it does in a *downward and forward direction*, the posterior margin (*f*) is screwed downwards and forwards until it assumes the position indicated by *j*; the anterior margin (*i d*) inclining more and more upwards and backwards, as shown at *g h*. This rotation of the posterior margin (*j*) round the anterior margin (*g h*) has the effect of causing the different portions of the under surface of the wing to assume various angles of inclination with the horizon, the wing attacking the air like a boy's kite. The angles are greatest towards the root of the wing and least towards the tip. They accommodate themselves to the speed at which the different portions of the wing travel—a small angle with a high speed giving the same amount of buoying power as a larger angle with a diminished speed. The screwing of the under surface of the wing (particularly the posterior margin) in a downward direction during the down stroke is necessary to insure a sufficient upward recoil, the wing being made to swing downwards and forwards pendulum fashion, for the purpose of elevating the body, which it does by acting upon the air as a long lever, and after the manner of a kite. During the down stroke the wing

beginning of the down stroke—the downward and forward rotation securing additional elevating power for the wing. The posterior margin of the wing in bats and birds, unless they are flying downwards, never rises above the anterior one, either during the up or down stroke.

is active—the air passive. In other words, the wing is depressed by a purely vital act. This is proved by taking a living or dead blow-fly, and forcibly depressing its wing in the direction of the head by the aid of a slender rod. This act causes the wing to make various angles of inclination with the horizon, as shown at *a b c d e f g* of fig. 18 ; but the instant the rod is removed the wing obliterates the angles in question, and flies in an upward and backward direction to its original position as indicated at *g h i j k l m* of fig. 19.

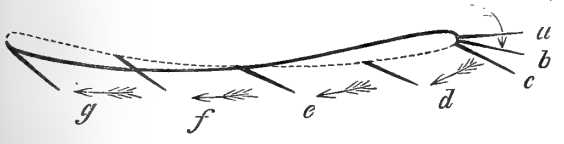


Fig. 18.

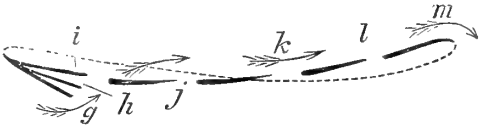


Fig. 19.

This shows very satisfactorily that while a voluntary effort is required to depress the wing, it is in some measure elevated, and the various inclined surfaces which it makes with the horizon changed by the aid of an elastic ligament or spring common to all wings. The down stroke is readily explained, and its results upon the body obvious. The real difficulty begins with the up or return stroke. If the wing was simply to travel in an upward and backward direction from *c* to *a'* of fig. 16, page 349, it is evident that it would experience much resistance from the superimposed air, and undo or negative the advantages secured by the descent of the wing. What really happens is this. The wing does not travel upwards and *backwards* in the direction *c b a'* of fig. 16 (the body be it remembered is advancing), but upwards and *forwards* in the direction *c d e f g*. This is brought about in the following manner. The wing is at right angles to the horizon (*x x'*) at *c*. It is therefore caught by the air because of the more or less horizontal travel of the body at 2, the elastic ligaments and other structures rotating the posterior or thin margin of the pinion in an upward direction, as shown at *g h i* of figure 19, page 351, and *d e f g* of figure 16, page 349. The wing by this partly vital and partly mechanical arrangement is rotated off the wind in such a manner as to keep its dorsal or non-biting surface directed upwards, while its concave or biting surface is directed downwards. The wing, in short, has its planes so arranged, and its angles so adjusted to the speed at which it is travelling, that it darts up a gradient like a true kite, as shown at *c d e f g* of figures 16 and 17, page 349. The wing consequently elevates and propels during its *ascent* as well as during its *descent*. It is, in fact, a kite during both the down and up strokes. The ascent of the wing is greatly assisted by the *forward* travel of the body. It is further assisted by the downward and forward fall of the body. This view will be readily understood by supposing, what is really the case, that the wing is more or less fixed by the air in space at 2 of figure 16, page 349, and that the body, the instant the wing is fixed, falls downwards and forwards

in a curve, which, of course, is equivalent to placing the wing above, and, so to speak, behind the insect—in other words, to elevating the wing preparatory to a second down stroke, as seen at *g* of figures 16 and 17, page 349.*

The Body ascends when the Wing descends, and vice versa.—The manner in which the body falls downwards and forwards in progressive flight is illustrated at figs. 20, 21, and 22.

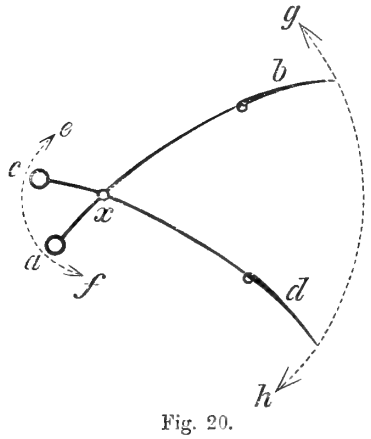


Fig. 20.

At fig. 20 the body is represented at *a* and *c*, the wing at *b* and *d*, *x* supplying the fulcrum or pivot on which the body and wing oscillate.

If the body (*a*) is elevated in the direction *e*, the wing (*b*) of necessity descends in the direction *h*. If, on the other hand, the body (*c*) descends in the direction *f*, the wing (*d*) ascends in the direction *g*. The ascent or descent of the wing is always very much greater than that of the body, from the fact of the pinion acting as a long lever. The remarks just made are true more especially of the body

* When a bird rises from the ground it runs for a short distance, or throws its body into the air by a sudden leap, the wings being simultaneously elevated. When the body is fairly off the ground, the wings are made to descend with great vigour, and by their action to continue the upward impulse secured by the preliminary run or leap. The body then falls in a curve downwards and forwards, the wings, partly by the fall of the body, partly by the reaction of the air, on their under surface, and partly by the contraction of the elevator muscles and elastic ligaments being placed above, and to some extent behind the bird—in other words, elevated. The second down stroke is now given, and the wings again elevated as explained, and so on "ad infinitum," the body falling when the wings are being elevated, and *vice versa*, as shown at fig. 14, p. 344. When a long-winged oceanic bird rises from the sea, it uses the tips of its wings as levers for forcing the body up, the points of the pinions suffering no injury from being brought violently in contact with the water. A bird cannot be said to be flying until the trunk is swinging forward in space and taking part in the movement. The hawk, when fixed in the air over its quarry, is simply supporting itself. To fly, in the proper acceptation of the term, implies to support and propel. This constitutes the difference between a bird and a balloon. The bird can elevate *and carry itself forward*, the balloon can simply elevate itself, and must rise and fall in a straight line in the absence of currents. When the gannet throws itself from a cliff the inertia of the trunk at once comes into play, and relieves the bird from those herculean exertions required to raise it from the water when it is once fairly settled thereon. A swallow dropping from the eaves of a house, or a bat from a tower, afford illustrations of the same principle. Many insects launch themselves into space prior to flight. Some, however, do not. Thus the blow-fly can rise from a level surface when its legs are removed. This is accounted for by the greater amplitude and more horizontal play of the insect's wing as compared with that of the bat and bird, and likewise by the remarkable reciprocating power which it possesses when the body of the insect is not moving forwards. (*Vide* figs. 3, 4, 5, and 6, page 338). When a beetle attempts to fly from the hand it extends its front legs and flexes the back ones, and tilts its head and thorax upwards so as exactly to resemble a horse in the act of rising from the ground. This preliminary over, whirr go its wings with immense velocity, and in an almost horizontal direction, the body being inclined more or less vertically. The insect rises very slowly, and often requires to make several attempts before it succeeds in launching itself into the air. I could never detect any pressure communicated to the hand when the insect was leaving it, from which I infer that it does not leap into the air. The bees, I am disposed to believe, also rise without anything in the form of a leap or spring. I have often watched them leaving the petals of flowers, and they always appeared to me to elevate themselves by the steady play of their

and wing when oscillating on either side of the fixed point x, this furnishing the fulcrum on which the body and the wing alternately act. The peculiarity, however, of the wing consists in the fact that it is a flexible lever and

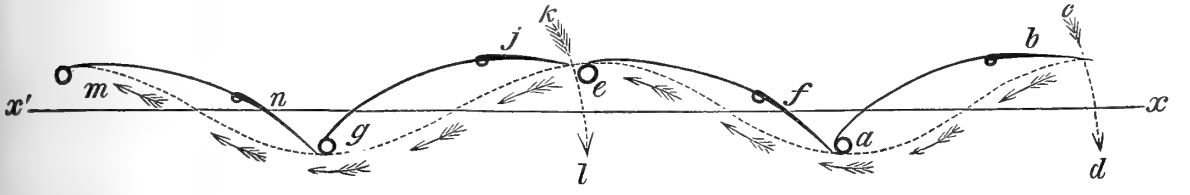


Fig. 21.

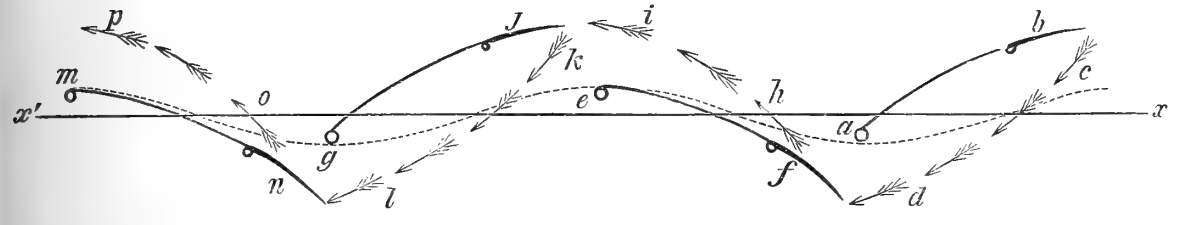


Fig. 22.

acts upon yielding fulcra (the air), the body participating in, and to a certain extent perpetuating the movements originally produced by the pinion. The part which the body performs in flight is illustrated at fig. 21. At a the body is depressed, the wing being elevated and ready to make the down stroke at b. The wing descends in the direction c d, but the moment it begins to descend the body moves *upwards and forwards* (see arrows) in a curved line to e. As the wing is attached to the body it is made gradually to assume the position f. The body is now elevated and the wing depressed, the under surface of the latter being so adjusted that it strikes upwards and forwards as a kite would. The body now falls *downwards and forwards* in a curved line to g, and in doing this it elevates or assists in elevating the wing to j. The pinion is a second time depressed in the direction k l, which has the effect of forcing the body along a waved track and in *an upward direction* until it reaches the point m. The ascent of the body necessitates the descent of the wing as at n. The body and wing, as will be seen from this figure, are alternately above and beneath a given line x x'. The same points are shown at fig. 22, the only difference being that the sweep of the wing is greater and the undulation made by the body less abrupt, as seen in vigorous flight. At a the body is depressed, and the wing (b) elevated high above the body. The pinion (b) descends in the direction c d, and forces the body in *an upward curve* to e. The body (e) is now elevated and the wing (f) depressed. The body (e) *falls downwards and*

wings, which was the more necessary, as the surface from which they rose was in many cases a yielding surface. The falling forward of the body during flight was indicated in my Memoir "On the Mechanism of Flight," Trans. Linn. Society, vol. xxvi. p. 226.

forwards in a curve to *g*, the pinion (*f*) by this act being made to describe the segment of a circle *h i j*, its under concave surface being applied to the air like a kite all the time. (It is thus that the wing elevates and sustains during the up stroke.) The wing (*j*) is made to descend in the direction *k l*, and forces the body (*g*) along *an upward curve* until it arrives at *m*, its subsequent fall elevating the wing (*n*) in the direction *o p*. Here again, the body and wing play alternately on either side of a given line *x x'*.

A careful study of figs. 20, 21, and 22 (pages 352, 353) shows the great importance of the twisted configuration and curves peculiar to the natural wing. If the wing was not curved in every direction it could not be rolled on and off the wind during the down and up strokes, as seen more particularly at fig. 22. This, however, is a vital point in progressive flight. The wing (*b*) is rolled on to the wind in the direction *c d*, its under concave or biting surface being crushed hard down with the effect of elevating the body to *e*. The body falls to *g*, and the wing (*f*) is rolled off the wind in the direction *h i*, and elevated partly by the action of the elevator muscles and elastic ligaments, and partly by the reaction of the air, operating on its under or concave biting surface, until it assumes the position *j*. The wing is therefore to a certain extent resting during the up stroke. The concavo-convex form of the wing is admirably adapted for the purposes of flight. In fact, the power which the wing possesses of always keeping its concave or under surface directed *downwards* and more or less *forwards* enables it to seize the air at every stage of both the up and down strokes so as to supply a persistent buoyancy. The action of the natural wing is accompanied by remarkably little slip—the elasticity of the organ, the resiliency of the air, and the contraction and relaxation of the elastic ligaments and muscles all co-operating and reciprocating in such a manner that the descent of the wing elevates the body, the descent of the body aided by the reaction of the air and the contraction of the elastic ligaments and muscles elevating the wing. The wing during the up stroke *arches above the body* after the manner of a parachute, and in turn prevents the body from falling. The sympathy which exists between the parts of a flying animal and the air on which it depends for support and progress is consequently of the most intimate character.

The up stroke (B of figures 16 and 17, page 349), as will be seen from the foregoing account, is a compound movement due in some measure to recoil or resistance on the part of the air—to the contraction of the muscles, elastic ligaments, and other vital structures, to the elasticity of the wing, and to the falling of the body in a downward and forward direction. The wing may be regarded as rotating during the down stroke upon 1 of figure 16, page 349, which may be taken to represent the long and short axes of the wing, and during the up stroke upon 2, which may be taken to represent the yielding fulcrum furnished by the air.

The same points are illustrated at 1 and 2 of figure 17, page 349, allowance being made in this case for the greater horizontal travel of the body during the down (A C) and up (B D) strokes, the increased horizontal travel of the body, as already pointed out, having the effect of diminishing the angles made by the under surface of the wing with the horizon during its vibrations.

The Wing acts upon Yielding Fulcra.—The chief peculiarity of the wing, as has been stated, consists in the fact that it is a twisted flexible lever specially constructed to act upon yielding fulcra (the air). The points of contact of the wing with the air are represented at *a b c d e f g h i j k l* respectively of figures 16 and 17, page 349, and the imaginary points of rotation of the wing upon its long and short axes at 1, 2, 3, and 4 of the same figures. The assumed points of rotation advance from 1 to 3, and from 2 to 4 (*vide* arrows marked *r* and *s*, fig. 17). The actual points of rotation correspond to the little loops *a b c d e f g h i j k l* of same figure; the descents of the wing to A and C, and the ascents to B and D. When the wing is in the position represented at *g* of figures 16 and 17, page 349, it is ready to begin a second down stroke, that is, it is screwed in a downward and forward direction. At *i* the second down stroke (C) is completed; at *i* the second up stroke is begun, the posterior margin of the wing being gradually rotated in an upward direction to prepare it for making the return or up stroke (D), as shown at *j k l m*. A third down stroke (E, fig. 16) is commenced at *m* and completed at *o*.

Weight contributes to Horizontal Flight.—That the weight of the body plays an important part in the production of flight may be proved by a very simple experiment. If two quill feathers are fixed into an ordinary cork, as represented at fig. 23, p. 356, and the apparatus is allowed to drop from a height, the cork does not fall vertically downwards, but *downwards* and *forwards* in a curve, and for the following reasons. The feathers *a b* are twisted flexible inclined planes, which arch in an upward direction. They are, in fact, true wings in the sense that an insect wing in one piece is a true wing. When dragged downwards by the cork (*c*), which would, if left to itself, fall vertically, they have what is virtually a down stroke communicated to them. Under these circumstances they inevitably dart forward; a struggle ensuing between the cork tending to fall vertically and the feathers tending to travel in a horizontal direction. As a consequence, the apparatus describes the curve *d e f g* before reaching the earth, *h i*. This is due to the action and reaction of the feathers and air upon each other, and to the influence which gravity exerts upon the cork. The forward travel of the cork and feathers, as compared with the space through which they fall, is very great. Thus, in some instances, they advanced as much as a yard and a half in a descent of three yards.

When artificial wings constructed on the principle of natural ones (*vide* fig. 24, p. 357), with stiff roots (*c, a*), tapering semi-rigid anterior margins (*a b, c d*), and

thin yielding posterior margins (*e f, g h*), are allowed to drop from a height (*r*), they describe double curves in falling, as shown at *m n o l, i j k l,* the roots of the wings (*c, a*) reaching the ground first, a circumstance which proves the greater buoying power of the tips of the wings. I might refer to many other experiments made in this direction, but sufficient have been adduced to show that weight, when acting upon wings, or, what is the same thing, upon elastic twisted inclined planes, must be regarded as an independent moving power. But

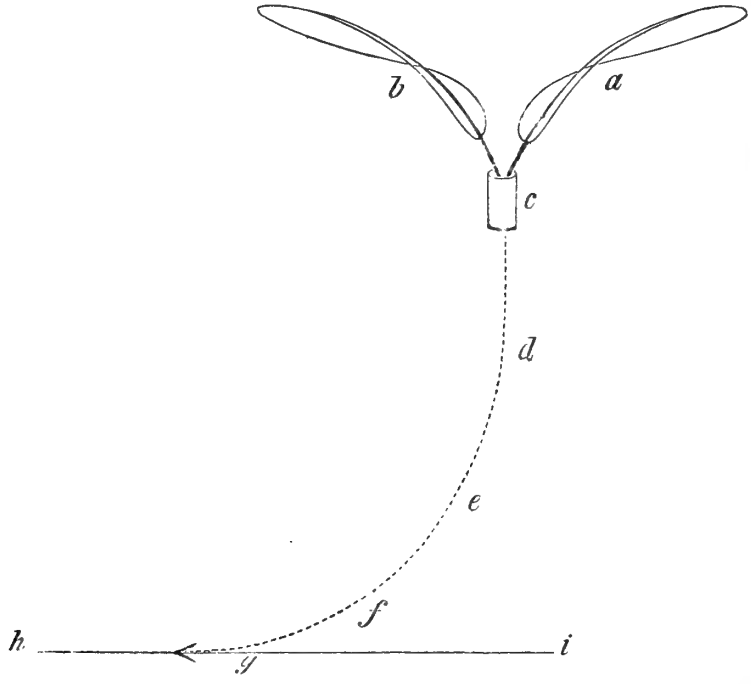


Fig. 23.

for this circumstance flight would be at once the most awkward and laborious form of locomotion, whereas in reality it is incomparably the easiest and most graceful.* The power which rapidly vibrating wings have of sustaining a body which tends to fall vertically downwards, is much greater than one would naturally imagine, from the fact that the body, which is always beginning to fall, is never permitted actually to do so. Thus, when it has fallen sufficiently far to assist in elevating the wings, it is at once elevated by the vigorous descent of those organs. The body consequently never acquires the downward momentum which it would do if permitted to fall through a considerable space uninterruptedly. It is easy to restrain even a heavy body when beginning to fall, while it is next to impossible to check its progress when it is once fairly launched into space and travelling rapidly in a downward direction (see footnote to page 371).

* The importance to be attached to weight in flight is variously explained in my Memoir on the subject, Trans. Linn. Society, vol. xxvi. pages 218, 219, 246, 260, and 261.

Mechanical Theory of the Action of the Insect's Wing as stated by CHABRIER.—In one instance only, according to CHABRIER,* are the muscles of flight in insects inserted directly into the root of the wing. This solitary example is

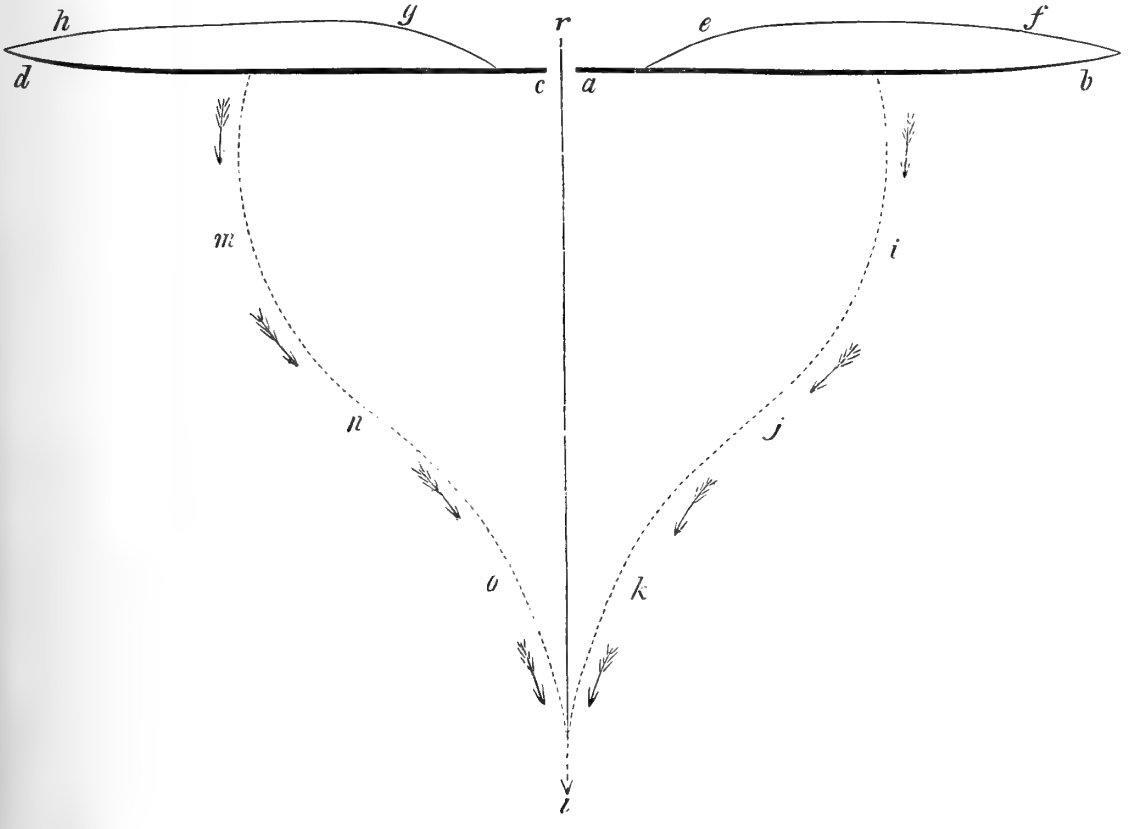


Fig 24.

the dragon-fly. CHABRIER regards the action of the insect's wing as purely mechanical. His argument may be stated in a few words. He observes, that whereas the muscles which propel the wings of the insect are, with one exception (the dragon-fly), confined to the interior of the thorax, that therefore they exert no direct influence upon the wings. He further gives it as his opinion, that the wings are actuated by the muscles *only during the down stroke,* and that the up stroke is entirely due to the reaction of the air—in fact, that if the wings only be depressed rythmically, the air will do the remainder of the work. Unfortunately for this theory there is no time to wait for the reaction of the air, the wings being driven with such velocity as necessitates their being partly elevated either by elastic ligaments or elevator muscles, in addition to the reaction of the air (*vide* page 345). CHABRIER, as will be seen, delegates to the air the task of reversing the planes of the wing, and of conferring upon it *those peculiar curves* which, overlooked by him, I have

* Mémoires du Muséum d'Histoire Naturelle. Tome septiéme. Paris, 1821. Essai sur le vol des Insectes, par I. CHABRIER, p. 297. Plates x. xi. and xii.

endeavoured to show are indispensable in flight. In short, he confides to the air the delicate task of arranging the details of flight—those details constituting in reality the most difficult part of the problem.

Objections to the Mechanical Theory of Wing Movements.—There are many facts which militate against CHABRIER'S mechanical theory of the movements of the insect's wing. I find, for example, that if the wing of the wasp, fly, humble bee, or butterfly be depressed by a delicate rod, its posterior margin is made to curve downwards, and to make various angles with the horizon (fig. 18, *a b c d e f g*, page 351); the wing, the instant the rod is removed, being flexed and elevated by the action of elastic ligaments which obliterate the angles formed during the depression (fig. 19, *g h i j k l m*, page 351). This implies the existence of a muscular system for depressing the wing, and a fibro-elastic system for elevating it, similar to what is found in the bat and bird, to be described presently. It also proves that the wing is jointed to the body in such a manner that it cannot either descend or ascend without changing the direction of its planes—the air taking no part in the change of plane referred to.

I find, secondly, that insects have the power of vibrating either wing by itself in any part of a radius not exceeding a half circle, and that the wing may be played above the body or on a level with or beneath it, as circumstances demand. These facts argue a much more intimate relation between the muscular system and the wings than CHABRIER is inclined to admit.

Thirdly, The wing in most insects is composed of two distinct portions at its root (figure 25, *a b*, p. 359), those portions being endowed with independent movements, which enable the insect to incline the anterior or thick margin (*a c f e*) of the wing in one direction, and the posterior or thin margin in another—to twist, in fact, the wing upon its long axis. This twisting of the wing upon its long axis exerts upon the organ precisely the same influence which the extending and flexing of the pinion does upon the wing of the bird and bat (figures 39, 40, 41, 42, and 43, p. 362). *It in short developes double figure of* 8 *curves along the anterior and posterior margins, and converts the wing into a screw capable of change of form.*

Fourthly, In the humble bee and other insects supplied with two pairs of wings geared to each other by hooklets, the posterior or thin margin of the first wing glides along the anterior or thick margin of the alula or second wing, which latter, acting as a long lever, has the power of adjusting the posterior or thin margin of the first wing.

Fifthly, In the wasp the first wing can be distinctly folded upon itself in the direction of its length, the alula or second wing folding upon the first wing previously folded, so that the area of the two wings is reduced to about one-third of what it was before the folding took place. When the wing is so folded it is very compact, and presents a well-defined cutting edge, which points in a backward direction.

I am induced to believe that the wing is folded after this fashion in certain cases during the back or return stroke, although the action of the pinion is so rapid that I have hitherto failed to make it out. The folding of the first wing upon itself in the wasp occurs in the line *g s* of fig. 25; the folding of the first wing upon itself and of the second upon the first, being seen at fig. 26 (*h d*); and the two wings, when folded and ready to make the return stroke, at fig. 27 (*d s*). The course pursued by the folded wings during the back stroke is indicated at *g h i j k l m* of fig. 19, page 351. Figure 28 represents the wing of

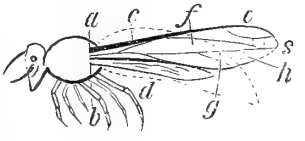


Fig. 25.

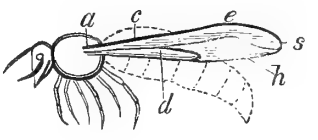


Fig. 26.

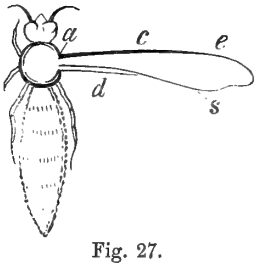


Fig. 27.

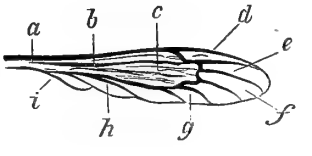


Fig. 28.

the crane-fly, which has, I believe, a similar action, the thin posterior margin, *f g h i*, being folded during the back or return stroke, and opened out during the forward stroke.

Sixthly, Many insects, such as the ephemera, beetles, locusts, &c., have assuredly the power of more or less completely crushing their wings together, and of alternately increasing and diminishing the wing area during the down and up strokes. The wings of most insects, moreover, are during the up stroke thrown into rugæ, which are flattened or altogether disappear during the down stroke. They further have the power of arching their wings during the up stroke, and of opening them out so as to increase their area during the down one. The butterfly affords an admirable example.

The Down and Up Stroke of the Wing of the Butterfly; Increase and Diminution of the Wing Area; Development of Figure of 8 *Curves on the Margins of the Wing.*—In the butterfly, as I have sufficiently satisfied myself, the first wing is made to pass above or over the second wing towards the termination of the down stroke, the convexity of both wings increasing meanwhile. This reduction in the wing area is necessary to destroy the momentum acquired by the wings during their descent, and to prepare them for making the up or return stroke. In the butterfly the wings strike downwards and forwards, and have a more vertical play than in almost any other insect. The wings are elevated

in the overlapped arched condition, and towards the end of the up stroke they are gradually separated to increase the area and prepare them for making the down stroke in a manner precisely analogous to what happens in bats and birds. They are then made to descend in their flattened condition, the first wing passing over the second towards the termination of the down stroke as just stated. Nor is this all. While the wings are being depressed and made to overlap more or less completely, and while they are being elevated and spread out, *double and opposite curves are being developed along their anterior, posterior, and outer margins.* This is a somewhat remarkable circumstance, as the butterfly is perhaps the most awkward flying creature that exists. It seems to prove that the presence of *double or figure of* 8 *curves,* is indispensable to flight. These points are illustrated at figs. 29, 30, 31, 32, 33, and 34. At *a,* of fig. 29, the

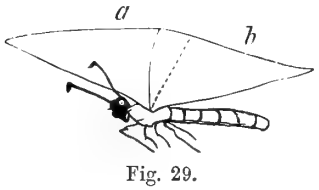


Fig. 29.

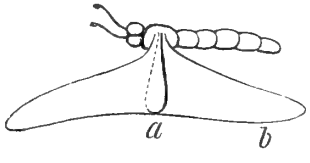


Fig. 30.

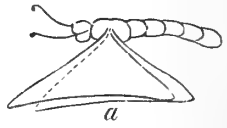


Fig. 31.

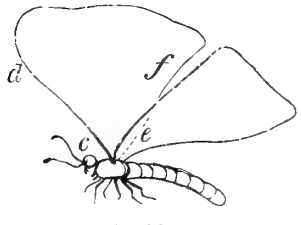


Fig. 32.

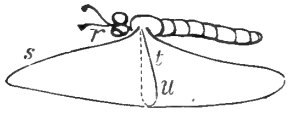


Fig. 33.

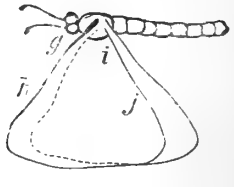


Fig. 34.

concavity of the first wing is directed downwards, the concavity of the second wing being directed slightly upwards as at *b.* The two curves taken together give a double or wave curve. In this figure the two wings are separated or spread out and ready to give the down stroke. At fig. 30 the two wings are separated to the utmost, and in the act of making the down stroke. Here the concavity of both wings is directed downwards as at *a,* a very small portion of the second wing only curving upwards (*b*). At fig. 31 the down stroke is completed, the first wing overlapping the second, and both being deeply concave on their under surfaces, as shown at *a.* They are now in a condition to make the up stroke, which is the reverse of the down one, and need not be described. The curves produced along the anterior and posterior margins of the wings of the butterfly during the up and down strokes are seen at figs. 32, 33, and 34. At fig. 32, the curves formed along the anterior (*c d*) and posterior (*e f*) margins of the first wing at the beginning of the down stroke, are represented. At fig. 33 the wing is represented, as seen at the middle of the down stroke, and the

curves referred to are nearly obliterated (*vide r s, t u*). At fig. 34 the wing is shown at the end of the down stroke, and the curves are reversed, as a comparison of *c d, e f* of fig. 32 with *g h, i j* of fig. 34 will satisfactorily prove.

In the dragon-fly *similar figure of* 8 *curves are developed along the anterior and posterior margins of the wings* at the beginning, middle, and termination of the down stroke, as an examination of figs. 35, 36, 37, and 38 will show. If

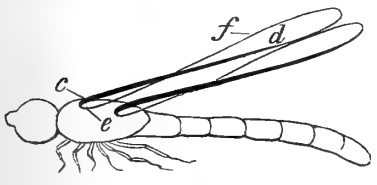


Fig. 35.

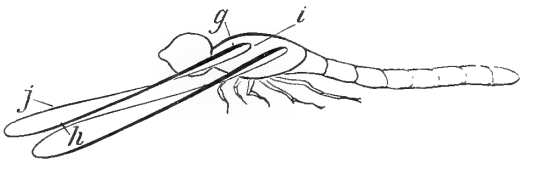


Fig. 36.

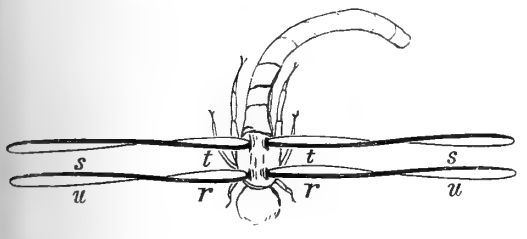


Fig. 37.

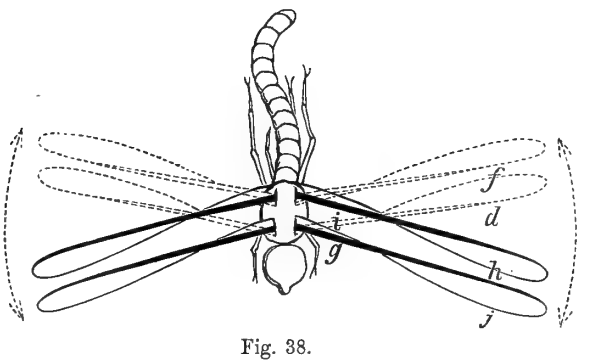


Fig. 38.

the letters *c d, e f* of fig. 35 (dragon-fly) be compared with corresponding letters of fig. 32 (butterfly); the letters *r s, t u* of fig. 37 (dragon-fly) with similar letters of fig. 33 (butterfly), and the letters *g h, i j* of fig. 36 (dragon-fly) with the same letters of fig. 34 (butterfly), it will at once be perceived that the curves which these letters represent are identical in both cases. At fig. 38 the wings are represented as seen at the beginning and end of the down stroke, the arrows *r, s* giving the range or play of the wings. The letters *d f* of this figure (anterior wing at beginning of down stroke) correspond with *d f* of fig. 35; the letters *g h i j* (anterior wing at end of down stroke) corresponding with similar letters in fig. 36. Fig. 38 shows how the posterior margin of the wing (*f*) is screwed *downwards and forwards* (*j*) during the down stroke (compare with *a, b, c* of figs. 16 and 17, page 349, and read remarks on the dragon-fly's wing at pages 335 and 350).*

* The wing area in insects is usually greatly in excess of what is absolutely required for flight, as the following experiments made with the common white and brown butterfly and dragon-fly will show :—

1. Removed posterior halves of first pair of wings of white butterfly. Flight perfect.

2. Removed posterior halves of first and second pairs of wings. Flight not strong but still perfect. If additional portions of the posterior wings were removed, the insect could still fly, but with great effort, and came to the ground at no great distance.

3. When the tips (outer sixth) of the first and second pairs of wings were cut away, flight was in no wise impaired. When more was detached the insect could not fly.

Curves in all respects analogous to those occurring in the wing of the butterfly and dragon-fly are observed in the wing of the bat and bird, as a reference to

Fig. 39.*

Fig. 40.

Fig. 41.

Fig. 42.

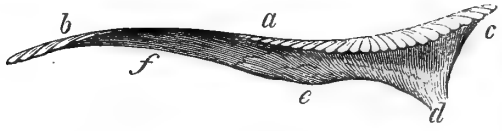


Fig. 43.

figs. 39, 40, 41, 42, and 43 will satisfy. They are also found in the rowing feathers of the wing of the bird, as shown at fig. 50, page 379.

4. Removed the posterior wings of the brown butterfly. Flight unimpaired.

5. Removed in addition a small portion (one-sixth) from the tips of the anterior wings. Flight still perfect, as the insect flew upwards of ten yards.

6. Removed in addition a portion (one-eighth) of the posterior margins of anterior wings. The insect flew imperfectly, and came to the ground about a yard from the point where it commenced its flight.

7. In the dragon-fly either the first or second pair of wings may be removed without destroying the power of flight. The insect generally flies most steadily when the posterior pair of wings are detached, as it can balance better; but in either case flight is perfect and in no degree laboured.

8. Removed one-third from the posterior margin of the first and second pairs of wings. Flight in no wise impaired.

If more than a third of each wing be cut away from the posterior or thin margin, the insect can still fly, but with effort.

Experiment 8 shows that the posterior or thin flexible margin of the wing may be dispensed with in flight. It is more especially engaged in propelling.

9. The extremities or tips of the first and second pair of wings may be detached to the extent of one third, without diminishing the power of flight.

If the mutilation be carried further, flight is laboured, and in some cases destroyed.

10. When the front edges of the first and second pair of wings are notched, or when they are removed, flight is completely destroyed.

This shows that a certain degree of stiffness is required for the front edges of the wings, the front edges indirectly supporting the back edges It is, moreover, on the front edge of the wing that the pressure falls in flight, and by this edge the major portion of the wing is attached to the body. The principal movements of the wing are in addition communicated to this edge.

Note.—Some of my readers will probably infer from the foregoing experiments, that the figure of 8 curves formed along the anterior and posterior margins of the pinion are not necessary to flight, since the tip and posterior margin of the wing may be removed without destroying it. To such I reply, that the wing is flexible, elastic, and composed of a congeries of curved surfaces, and that so long as a portion of it remains, it forms, or tends to form, figure of 8 curves in every direction.

* Figures 39, 40, 41, 42, and 43 show the double curves which occur on the anterior (*b a c*) and posterior (*d e f*) margins of the wing of the bat and bird.

Consideration of the Forces which Propel the Wings of Insects.—Proceeding now to a consideration of the forces which propel and regulate the wings of insects, I find that in the thorax of the insect the muscles are arranged in two principal sets in the form of a cross—*i.e.*, there is a powerful vertical set which runs from above downwards, and a powerful antero-posterior set which runs from before backwards. There are likewise a few slender muscles which proceed in a more or less oblique direction. The antero-posterior and vertical sets of muscles are quite distinct, as are likewise the oblique muscles. Portions, however, of the vertical and oblique muscles terminate at the root of the wing in jelly-looking points which greatly resemble rudimentary tendons, so that I am inclined to believe that the vertical and oblique muscles exercise a direct influence on the movements of the wing. The contraction of the antero-posterior set of muscles (indirectly assisted by the oblique ones) elevates the dorsum of the thorax by causing its anterior extremity to approach its posterior extremity, and by causing the thorax to bulge out or expand laterally. This change in the thorax necessitates the descent of the wing. The contraction of the vertical set (aided by the oblique ones) has a precisely opposite effect, and necessitates its ascent. While the wing is ascending and descending the oblique muscles cause it to rotate on its long axis, the bipartite division of the wing at its root, the spiral configuration of the joint, and the arrangement of the elastic and other structures which connect the pinion with the body, together with the resistance it experiences from the air, conferring on it the various angles which characterise the down and up strokes. The wing may therefore be said to be depressed by the contraction of the antero-posterior set of muscles, aided by the oblique muscles, and elevated by the contraction of the vertical and oblique muscles, aided by the elastic ligaments, and the reaction of the air. If we adopt this view we have a perfect physiological explanation of the phenomenon, as we have a complete circle or cycle of motion, the antero-posterior set of muscles contracting when the vertical set of muscles are relaxing, and *vice versa*, an arrangement which gives an equal period of activity and repose to both sets. This, I may add, is in conformity with all other muscular arrangements, where we have what are usually denominated extensors and flexors, but which, as I have shown elsewhere,* are simply the two halves of a circle of muscle and of motion, an arrangement for securing diametrically opposite results in limbs and the condition of activity and rest in muscles.

Chabrier's account, which I subjoin, virtually supports this hypothesis :—

"It is generally through the intervention of the proper motions of the dorsum, which are very considerable during flight, that the wings or the elytra are moved equally and simultaneously. Thus, when it is elevated, it carries

* On the Mechanical Appliances by which Flight is attained in the Animal Kingdom, Trans. Linn. Society, vol. xxvi. pages 200, 201, and 262.

with it the internal side of the base of the wings with which it is articulated, from which ensues the depression of the external side of the wing; and when it approaches the sternal portion of the trunk, the contrary takes place. During the depression of the wings the dorsum is curved from before backwards, or in such a manner that its anterior extremity is brought nearer to its posterior, that its middle is elevated, and its lateral portions removed further from each other. The reverse takes place in the elevation of the wings; the anterior extremity of the dorsum being removed to a greater distance from the posterior, its middle being depressed, and its sides brought nearer to each other. Thus its bending in one direction produces a diminution of its curve in the direction normally opposed to it; and by the alternations of this motion, assisted by other means, the body is alternately compressed and dilated, and the wings are raised and depressed by turns." *

Objections to Mechanical Theory of Insect Wing Movements specified.—The objections to CHABRIER'S mechanical theory of the action of insects' wings may be briefly stated :—

First, The movements of the wings of insects are not necessarily absolutely synchronous. On the contrary, insects have the power of moving their wings independently.

Second, Insects can twist or plait their wings at the root—the butterfly having the power of causing the one wing to overlap the other when required.

Third, Insects can increase the convexity of their wings during the up stroke and decrease it during the down stroke.

Fourth, They can in some cases fold and diminish the area of the wing during the up stroke and increase it during the down one.

Fifth, In the dragon-flies we can without difficulty trace the muscles terminating in the roots of the wings—a presumptive proof that in other insects there is a direct connexion between the muscles of the thorax and the wings they are destined to move.

Sixth, All insects have the power of elevating their wings when dressing them, so that the reaction of the air is not necessary to the up stroke, although it certainly contributes to it in flight. They can, moreover, during the intervals of rest, develope figure of 8 curves along the anterior and posterior margins of the pinion independently of the air.

Seventh, There are muscles in the dragon-fly, and I believe in other insects also, delegated to elevate as well as depress the wing.

Eighth, There are elastic ligaments which recover or flex and *partly elevate the wing* when the organ is depressed artificially and not engaged in flight. In

* "General Observations on the Anatomy of the Thorax in Insects, and on its Functions during Flight." By E. T. BENNETT, F.L.S., &c. (Extracted chiefly from the "Essai sur le vol des Insectes," par J. CHABRIER, Mém. du Muséum d'Histoire Naturelle. Zool. Journal, vol. i. art. xlvi. 1825.)

such cases the air can exert no influence whatever, as the wing is depressed gently, expressly to avoid recoil.

We have therefore the conditions of flight developed to nearly as great an extent in the insects as in the bats and birds. That distinct elevator and depressor muscles exist in the bat and bird, and that these act in conjunction with elastic ligaments there can be no doubt whatever, see pages 395, 396, and 397.

Wings Mobile and Flexible as well as Elastic—Elasticity, Flexibility, and Mobility not to be confounded—Mobility and Flexibility necessary to Flight.—Much importance has been attached by ancient and modern authors to the elastic properties of the wing, and not a few recent investigators are of opinion that flight is mainly due to the yielding of the wing to the impact of the air on its under surface during the down stroke. That, however, the mere elasticity of the pinion, if regarded apart from its mobility and flexibility, avails little may be proved in a variety of ways. By mobility I mean that power which the wing enjoys of moving at its root in an upward, downward, forward, backward, or oblique direction, and likewise the remarkable property which it possesses of rotating or twisting in the direction of its length. I also include under the term mobility the additional power possessed by bats and birds of opening and closing, *i.e.*, of flexing and extending the wings during the up and down strokes, as well as the power enjoyed by the bat of moving its fingers, and by the bird of moving its individual primary, secondary, and tertiary feathers at their roots. By the flexibility of the wing, I mean that power which the wing possesses of throwing itself into a great variety of curves during its action—these curves being formed, reversed, or obliterated at the will of the flying animal. It is necessary to distinguish between mobility, flexibility, and mere elasticity, because any rotation of the wing along its anterior or thick margin is at once followed by an elevation or depression of its posterior or thin margin, which elevation or depression is almost invariably and wrongly attributed to elasticity. That the wing is elastic throughout, and that its posterior or thin margin yields slightly (to prevent shock) when it attacks the air there can be no doubt. The yielding, however, is very slight, and it is always accompanied by a certain degree of rotation or torsion. If it were otherwise—if the posterior margin of the wing yielded to any marked extent in an upward direction when the wing descended, it is evident that the air on which the wing depended for support would escape from under it, and flight as a consequence be rendered abortive. It is the air more than the wing which yields or gives way in flight, and the yielding that occurs in the wings, is to be traced for the most part, to a rotation of the wing along its anterior margin—to movements occurring in the muscles and ligaments, and in the bones and feathers when present, particularly at the root of the feathers. These remarks are true of living wings. It is not, however, to be inferred from what is here stated that natural wings

may not be successfully imitated, both in their structure and movements, by mechanical appliances in which elasticity plays a very prominent part. On the contrary, I am prepared to show further on, that flight may be regarded as a purely mechanical problem, and that it admits of a mechanical solution. I am, however, desirous of showing in the first place what movements are vital, what vito-mechanical, and what mechanical *in natural flight.* This done, we will then be in a position to enter upon a consideration of artificial flight. That elasticity of itself will not produce flight may be inferred from the following experiments. If, for instance, we lash light unyielding reeds to the anterior margins of a pigeon's wings so as to prevent flexion at the elbow-joints, we instantly destroy flight. In this experiment the *elasticity* of the wings, and particularly of the rowing feathers, is in no wise impaired; in reality the mobility and flexibility of the wings only are interfered with. A still more conclusive proof is to be found in the fact that in insects the most *elastic portions* of the wings can be *altogether removed* without destroying the power of flight. Thus I have cut away as much as two-thirds from the posterior margin of either wing of the blow-fly, and yet the insect flew with remarkable buoyancy. I have also removed portions of the tips of the wings with impunity. I made similar experiments with the dragon-fly, butterfly (pages 361 and 362), and sparrow, and with nearly uniform results.

Analysis of the Down and Up Strokes in the Wing of the Bird and Bat.— What was said of the movements of the wing of the insect holds equally true of those of the bat and bird, if allowance be made for the more vertical direction of the down and up strokes, and for the fact that the wings of the bat and bird are in several pieces and jointed.* The joints, like the muscles, extend in the direction of the length of the wing; thus, in addition to the shoulder-joint, we have the elbow, wrist, and finger joints. The insect, bat, and bird have the shoulder joint in common, and this joint is so constructed that the wing is free to move in an upward, downward, forward, backward, and oblique direction. It also admits of a certain amount of rotation or torsion in the direction of the length of the wing. The joint is in fact universal in its nature. Another feature possessed in common by insects, bats, and birds, is the elastic ligaments which recover and partly elevate the wing during the up stroke. Those ligaments in the bat and bird are not confined to the root of the wing, but extend along its margins even to its tip.

The presence of those ligaments shows that the wing is not elevated exclusively by the reaction of the air. There are, moreover, distinct elevator muscles in the wing of the bat and bird. The presence of voluntary muscles, and of elastic and other ligaments, afford important indications in the construction and

* The beetles have also their wings jointed.

application of artificial wings, and I find that by employing a ball and socket joint, and a cross system of elastic bands at the root of the wing, I can imitate the movements of the natural wing with remarkable precision. By adopting the springs referred to—by making the wing elastic in all its parts, even along its anterior or thick margin (natural wings are elastic in this situation), and by applying a power which varies in intensity, I can communicate to an artificial wing a vibratory motion, completely devoid of *pauses or dead points.* The working of the wing in question is accompanied with very little slip. Indeed, the slip is so little that the wing may be said to supply a persistent buoying and propelling power. When the wing is made to vibrate briskly in a more or less vertical direction, it leaps forward in a series of curves, the down stroke running into the up one and *vice versa,* to form a continuous upward wave track. The power applied is greatest at the beginning of the down stroke. It is decreased at the end of the down stroke, slightly increased at the beginning of the up stroke, and again decreased towards the termination of that act. Those changes in the intensity of the driving power are necessary to allow the air time to react on the under surface of the wing, and to bring the elastic properties of the springs and of the wing into play. The springs should be arranged at right angles and obliquely, that is, there should be a superior, inferior, anterior, and posterior set running at right angles to each other, and between these as many oblique springs as are deemed necessary. The springs ought to vary as regards their length and their strength. Thus, the superior springs, which assist in elevating the wing, ought to be longer and stronger than the inferior ones; and the posterior springs, which restrain the wing from leaping forwards during its vibrations, should be longer and stronger than the anterior ones, the wing having no tendency to travel backwards. A detailed account of the structure and movements of artificial wings will be found at the end of the present memoir.

In the bat and bird the wing is extended or pushed away from the body prior to the down stroke, and folded or drawn towards the body prior to the up stroke. The unfolding or extending of the wing prior to the down stroke, as seen in the gull, is shown at Plate XI. figures 3, 2, 1, 5; Plate XIV. figure 18.

When the wing is being extended or opened out it is also being elevated, as shown at 1, 2, 3 of Plate XI. figure 5, and Plate XIV. figure 18. When the wing is flexed, as at *t p* of figure 3, Plate XI., the under surface of the wing (*s q*) is nearly on a level with the horizon (*b d*). When, however, the wing is partially extended, as at Plate XI. figure 2, the angle which its under surface makes with the horizon is considerable, *c b d* representing the angle, and *b d* the horizon. When the wing is fully extended, and ready to give the down stroke, the angle which the under surface of the wing makes with the horizon is still more increased, as shown at Plate XI. figure 1, *c b d* indicating the angle, and *b d* the horizon. The angle made by the under surface of the root

of the wing with the horizon considerably exceeds that made by the tip, and is much greater than a casual observer would be inclined to admit. It is obscured by the curving downwards and forwards of the anterior margin of the wing towards the root, as seen at *a* of figure 7, Plate XII. In this figure the apparent angle made by the root of the wing with the horizon (*e f*) is *a b d*, the real angle being *c b d*. The wing of the bird rotates in opposite directions during extension and flexion. The various angles of inclination made by the wing of the gannet in extension and flexion is well shown at Plate XIII. figures 16 and 17.

In figure 17 (flexion) the posterior margin of the wing (*s q p o*) is on a level with the body of the bird; whereas in figure 16 (extension) the posterior margin (*q p o*) is directed downwards and forwards, as indicated by the arrows. The same thing is seen in the pea-wit, at Plate XII. figure 8. In this figure the wing to the right of the observer is flexed, and in the act of making the up stroke, the anterior margin of the pinion being slightly directed downwards (*vide* arrow). The wing to the left of the observer is, on the contrary, extended, and in the act of making the down stroke, the anterior margin of the pinion being directed upwards (*vide* arrow).

The rotation of the posterior margin around the anterior as an axis during extension, is occasioned by the points of insertion of the pectoralis major and other muscles, by the attachments and directions of the elastic and other ligaments, and by the spiral nature of the articular surfaces of the bones of the wing—the mere act of extension on all occasions involving the rotation in question.

The Wing of the Bird Descends as a Long Lever.—Let us imagine the wing fully extended and elevated, and making a certain angle with the horizon, as indicated at *c b d* of figure 1, Plate XI., at 3 of figure 5, Plate XI., and at 3′ of figure 18, Plate XIV. The wing is now prepared to make the down stroke, and descends in a spiral swoop, successively assuming the position 4 in figure 19, Plate XIV., and 4 in figure 6, Plate XI. It acts with extreme energy as a long lever (*vide c d* of figure 6, Plate XI.), the purchase which it has on the body being much greater than is usually anticipated.

During its descent the angle which the wing makes with the horizon is increased, as shown at *a b c* of figures 16 and 17 (page 349), the horizon in these figures being indicated by the straight line *x x′*.

In the bird, therefore, as in the insect, the posterior or thin flexible margin of the wing is screwed down upon the air while the wing is descending.

The Rotation of the Posterior Margin of the Wing in a Downward Direction increases the Elevating, but diminishes the Propelling Power of the Wing.—The additional hold which the bird can cause its wing to take of the air by resorting to a greater or less degree of rotation, is truly surprising. If the wing is depressed *minus* the rotation, it darts forward, but takes no very decided catch

of the air. As a consequence, the recoil is feeble. If, however, the rotation is added, the wing seizes the air with such avidity as in all cases to produce a very violent reaction. The tendency of the wing to dart forward is diminished by the rotation, but the actual elevating power of the pinion is greatly augmented. This point can be readily ascertained by depressing and screwing, in the manner described, the wing of the swan or of any other large bird, previously dried, in the extended position. In preparing the wing for the experiment care should be taken not to destroy the curves peculiar to the natural extended wing. I mention this fact because, of many swans' wings prepared by me for this purpose, I found one had been inadvertently flattened, and gave quite an indifferent result.

The Importance to be attached to the Concavo-Convex Form of the Wing in Birds.—The downward screwing of the concave or under surface of the wing, which is so efficacious in securing a powerful hold of the air during the down stroke, is followed during the up stroke by an upward screwing of the convex or upper surface, which is not less effective in evading the air. In fact, when the wing ascends it is drawn towards the body, and deeply arched, so that it is literally made to roll upwards, its convex or dorsal surface being directed upwards throughout the entire up stroke. It is thus the wing evades the superincumbent air during the return stroke. This account will be readily understood by a reference to figures 13, 14, and 15, Plate XIII.

At figure 15, Plate XIII., the wing is represented as seen in the middle of the down stroke. It is widely spread out, and finely arched. At figure 14, Plate XIII., the wing is shown as observed towards the end of the down stroke—the wing being partly flexed or drawn towards the body, and the arch rendered more abrupt, particularly towards the root of the pinion. At figure 13, Plate XIII., the wing is seen quite at the termination of the down stroke. It is fully flexed, and drawn still closer to the body. It is, moreover, more deeply arched than in either of the other figures. It has, in fact, assumed the shape which offers least resistance in an upward direction, and is prepared to make the up stroke.

The Under or Concave Biting Surface of the Wing of the Bird effective both during the Down and Up Strokes.—If, instead of believing that *the wing is elevated*, we believe what, as I have already stated is actually the case, viz., that *the body of the bird falls downwards and forwards*, we at once transfer the resistance from the dorsal or convex non-biting surface of the wing to the ventral concave or biting surface—the body being supported while the wings are being elevated by a beautifully arched natural parachute formed by the wings. The elevation of the wings is, in short, in a great measure a consequence of the falling of the body. It is in this way that the air comes to assist in elevating the wings. The air, in short, caught under the wings is instrumental in elevating and extending them in proportion as the body falls (*vide* figures 13, 14, and 15, Plate XIII.) The small size of the elevator muscles of the wing of the

bird and bat, as compared with the very powerful depressor muscles, is thus accounted for. The elevation of the wing, as will be inferred, is to a certain extent a mechanical act, and is due to the reaction of the air, the contraction of the elastic ligaments, and the downward and forward fall of the body. It is, however, not altogether mechanical, the wing, as I shall show subsequently, being perfectly under control both during the down and up strokes.

Lax Condition of the Shoulder Joint in Birds, &c.—The great laxity of the shoulder joint readily admits of the body falling downwards and forwards during the up stroke. This joint, as has been already stated, admits of movement in every direction, so that the body of the bird is like a compass set upon gimbals, *i.e.*, it swings and oscillates, and is equally balanced, whatever the position of the wings. The movements of the shoulder joint in the bird, bat, and insect, are restrained within certain limits by a system of check ligaments and prominences; but in each case the range of motion is very great, the wing being permitted to swing forwards, backwards, upwards, downwards, or at any degree of obliquity. It is also permitted to rotate along its anterior margin, or to twist in the direction of its length to the extent of nearly a quarter of a turn. This great freedom of movement at the shoulder joint enables the insect, bat, and bird, to rotate and balance upon two centres—the one running in the direction of the length of the body, the other at right angles, or in the direction of the length of the wings.

The Wings Elevated Indirectly by the Operation of Gravity.—I have explained that during the up stroke the body falls, and the wings are elevated. Let us now, for the sake of argument, advocate an opposite view. Let us take for granted that the body is fixed in space, and that the wings are elevated by a purely vital act. From this it follows that the wings during their ascent will of necessity experience much resistance from the superimposed air, the rounded form of the upper or dorsal surfaces of the pinions diminishing, but not removing the evil.

The resistance experienced by the wings during their ascent is obviated in the simplest manner possible, the movement, as has been explained, being dexterously transferred from the wings to the trunk in such a manner that the under or concave surfaces of the wings are made to act in lieu of the upper or convex surfaces. The body, in a word, is dragged downwards by the inexorable power of gravity; but the descent of the body involves the ascent of the wings. The body and wings, therefore, reciprocate, the body being elevated by the descent of the wings in conjunction with other means, while the wings are elevated to a great extent by the descent of the body, as shown at figures 20, 21, and 22, pages 352 and 353.* The wings are also partly elevated by the reaction elicited from the air—the contraction of the elevator muscles and elastic ligaments and the forward travel

* The alternate ascent and descent of the wings and body during the down and up strokes are well seen in the butterfly and in all animals whose wings are large for their bodies.

of the body. The space through which the body descends when the wings ascend is very trifling, from the fact that the body is situated at the roots of the wings—a very slight movement at the roots of the pinions necessitating an extensive movement at the tips. This explains the very small waved track made by the body in progressive flight as compared with that made by the wings. (Contrast 1, 2, 3, 4, 5 of figure 14 page 344, with *a c e g i* of the same figure.)

The Wings of the Bird form a Natural Parachute from which the Body Depends both during the Down and Up Strokes.—The falling downwards of the body, and the gradual expansion and elevation of the wings during the up stroke, is seen at Plate XIII. figures 13, 14, and 15. At figure 13 the wings and the body are in the position peculiar to them at the end of the down stroke, *i.e.*, the body is elevated and the wings depressed. The up stroke is commenced, and the body falls, while the wings are somewhat expanded and elevated, as at Plate XIII. figure 14. The body falls still more, and the wings are further elevated and expanded, as seen at Plate XIII. figure 15. The wings are now on a level with the body of the bird, and mark how beautifully the latter is buoyed up. The body is attached to, and suspended from, a wide-spread finely arched parachute. The body goes on falling, and the wings rising, till the body is depressed and the wings elevated, as seen at 2, 2′ and 3, 3′ of figure 18, Plate XIV. This terminates the up stroke, and it will be observed that the position of the body is just the reverse of what it was at the beginning of the up stroke. At the beginning of the up stroke, the body was highest and the wings lowest (*vide* figure 13, Plate XIII.) At the end of the up stroke, the body is lowest and the wings highest (*vide* 3, 3′ of figure 18, Plate XIV.) That the body is supported and carried forward during the up stroke of the wings is proved beyond doubt by the experiment described at pages 355, 356, and illustrated by figure 23. If the quill feathers *a*, *b*, of figure 23 (p. 356) be compared with the two wings 3, 3′ of figure 18, Plate XIV., and the cork *c* of figure 23 with the body of the bird in figure 18, Plate XIV., it will be found that the conditions are the same in both, and that both are to a great extent sustained and carried forward in space, the one by the overarching feathers and the other by the overarching wings.* Perhaps the simplest illustration that can be given of

* *Weight necessary to Flying Animals as at present constructed—Weight and Levity relatively considered with regard to Aërial and Subaquatic Flight* (Diving).—Captain W. F. Hutton, in a recent pamphlet (On the Sailing Flight of the Albatros, Phil. Mag., August 1869), contends, that whereas a bird lighter than the water can fly in it, so, in like manner, a bird lighter than the air could fly in this medium, and that therefore *weight* is not necessary to aërial flight. Captain Hutton, however, forgets that a bird destined to *fly above* the water is provided with travelling surfaces so fashioned and so applied (they strike from *above downwards and forwards*), that if it was lighter than the air, they would carry it off into space without the possibility of a return ; in other words, the action of the wings would carry the bird obliquely upwards, and render it quite incapable of flying either in a horizontal or downward direction. In the same way a bird destined to *fly under* the water (auk and penguin), if it was not lighter than the water, such is the configuration and mode of applying its travelling surfaces (they strike *from below upwards and backwards*), they would carry it in the direction of the bottom

the mutual action and reaction of the body and wings during the up stroke is that furnished by a partly opened umbrella, whose handle has been intentionally weighted. If the umbrella thus prepared be dropped from a height, the

without any chance of return to the surface. In aërial flight, weight is the power which nature has placed at the disposal of the bird for regulating its altitude and horizontal flight, a cessation of the play of its wings, aided by the inertia of its trunk, enabling the bird to approach the earth. In subaquatic flight, levity is a power furnished for a similar but opposite purpose; this, combined with the partial slowing or stopping of the wings and feet, enabling the diving bird to regain the surface at any moment. Levity and weight are auxiliary forces, but they are necessary forces when the habits of the animals, and the form and mode of applying their travelling surfaces are taken into account. If the aërial flying bird was lighter than the air, its wings would requite *to be twisted round* to resemble the diving wings of the penguin and auk. If, on the other hand, the diving bird (penguin or auk) was heavier than water, its wings would require to resemble aërial wings, and they would require to strike in an opposite direction to that in which they strike normally. From this it follows that *weight* is necessary to the bird (as at present constructed) destined to navigate the air, and *levity* to that destined to navigate the water. If a bird was made very large and very light, it is obvious that the diving force at its disposal would be inadequate to submerge it. If, again, it was made very small and very heavy, it is equally plain that it could not fly. Nature, however, has struck the just balance; she has made the diving bird, which flies under the water, relatively much heavier than the bird which flies in the air, and has curtailed the travelling surfaces of the former, while she has increased those of the latter. For the same reason, she has furnished the diving bird with a certain degree of buoyancy, and the flying bird with a certain amount of weight—levity tending to bring the one to the surface of the water, weight the other to the surface of the earth, which is the normal position of rest for both. The action of the subaquatic or diving wing of the king penguin is well seen in the annexed woodcut (Fig. 44).

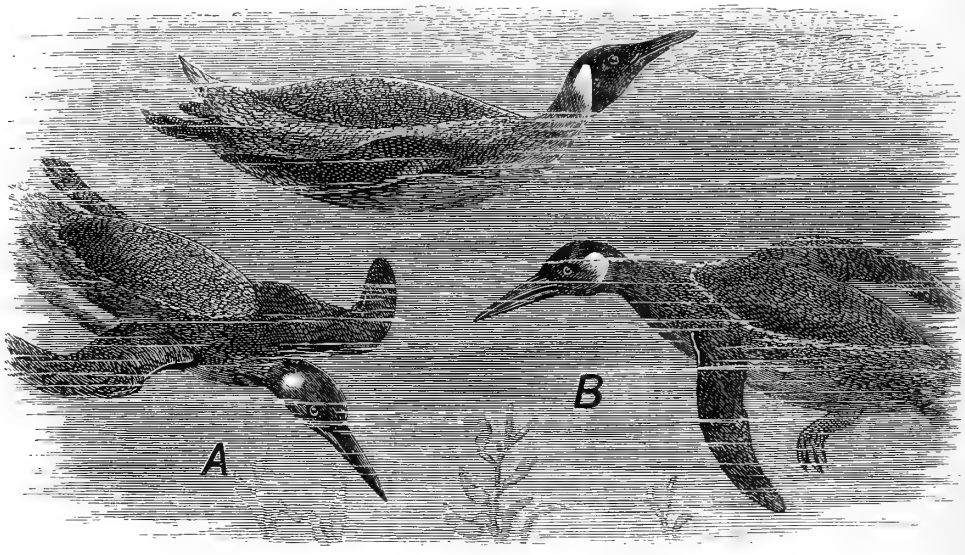


Fig. 44.

At A, the penguin is in the act of diving, and it will be observed that the anterior or thick margin of the wing is directed downwards and forwards, while the posterior margin is directed upwards and backwards. This has the effect of directing the under or ventral concave surface of the wing *upwards* and *backwards*, the effective stroke being delivered in this direction. The efficacy of the wing in counteracting *levity* is thus obvious. At B, the penguin is in the act of regaining the surface of the water, and in this case the wing is maintained in one position, or made to strike downwards and forwards like the aërial wing, the margins and under surface of the pinion being reversed for this purpose. The object now is not to depress but to elevate the body. Those movements are facilitated by the alter-

falling of the weighted handle will have the effect, in conjunction with the resistance which the under concave surface of the umbrella experiences from the air, of opening it up, precisely as the wings are opened up and elevated at figures 13, 14, and 15, Plate XIII. And if it so happens that the steels of the umbrella are feeble, and the weight attached to the handle sufficiently great, the umbrella will be more or less everted, as shown at 2, 2′ and 3, 3′ of figure 18, Plate XIV. If the frame of the umbrella was endowed with vitality, and had the power of quickly regaining its original form, it would elevate the weighted handle, and so attain its original position. A repetition of those changes, if the proper degree and kind of power were added, would result in flight, particularly if one side of the umbrella was rendered more rigid than the other, as this would have the effect of conferring an eccentric action upon it. The parachute principle here advocated is corroborated to a certain extent by the flight of the beetles. In these, in some cases, the *elytra* or wing cases are deeply concavo-convex. The membranes or true wings strike in a downward, forward, and more or less horizontal direction, and in so doing they force the air forward under the ventral or concave surfaces of the elytra or false wings, which are thus converted into parachutes or tiny sustaining balloons. That the elytra perform a very important function in flight is proved by the fact that when they are removed the insect cannot fly. I had ocular demonstration of this at Somerton, Wexford, in the summer of 1868. When I amputated the elytra close to the roots, the insects could not rise, although they made frequent attempts to do so. The elytra or false wings and the membranous or true wings form, when extended, deeply concave or umbrella shaped surfaces, the peculiarity in such instances being that the umbrellas formed by the true wings move and are active; whereas those formed by the elytra are fixed or immobile, and consequently passive.

The Wing of the Bird elevated as a Short Lever.—In birds with short rounded wings, and in others with longer wings, in forced flight the wing is usually elevated as a short lever, as shown at 6 of figures 6 and 19, Plates XI. and XIV., and 1 of figures 5 and 18, Plates XI. and XIV.; it being extended or spread out quite towards the end of the up stroke, as represented at 1, 2, 3 of figures 5 and 18, Plates XI. and XIV. In birds with long pointed wings, when flying leisurely, the wing is not unfrequently expanded at the middle of the up

nate play of the feet. What strikes one in the present woodcut is the comparatively small size of the diving or swimming wing, which resembles the flipper of the turtle, seal, sea bear, and walrus. At Plate XIII. figure 15, the aërial wing, as seen in the gull, is represented, and the large size of the flying pinion, as compared with the diving subaquatic one, is at once apparent. Here the anterior margin (*x s t v w*) of the wing is directed upwards and forwards, the posterior one (*o p q*) downwards and backwards. This causes the under or ventral concave surface of the pinion to look *downwards and forwards*, the direction in which the effective or down stroke is delivered. The aërial wing, like the subaquatic wing, *is twisted upon itself*. It strikes *downwards and forwards*, because this is the direction in which a body in motion would naturally fall.

stroke, as seen at 4 of figure 19, Plate XIV., and at figure 15, Plate XIII.; and it is no doubt this circumstance which has induced hasty generalisers to deny that the wing is flexed during the up stroke. This is a pardonable mistake, as the wing in such cases may be actually extended for two-thirds of the up stroke. When the wing is fully flexed and elevated as a short lever, its rowing feathers are separated and opened up, and the bird draws largely upon its vital resources. When, on the other hand, the wing is elevated as a long lever, and is wielded in one piece, after the manner of the insect wing, the bird takes advantage, to a great extent, of the numerous mechanical adaptations with which nature has endowed it. The flight of the albatros furnishes the best example. The opening up of the feathers during the up stroke facilitates the ascent of the pinion, and permits a more rapid action. The separation of the feathers is, however, not necessary to successful flight, the bat flying remarkably well by the aid of a continuous membrane which, as is well known, is destitute of feathers.

The Wing Vibrates Unequally on either Side of a given Line.—The wing, during its vibration, descends further below the body than it rises above it. This is necessary for *elevating purposes.* In like manner the posterior margin of the wing (whatever the position of the organ) descends further below a given line than it ascends above it. This is requisite for *elevating and propelling purposes,* the under surface of the wing being always presented at a certain upward angle to the horizon, and acting as a true kite. This view is fully explained at p. 345. If the wing oscillated equally above and beneath the body, and if the posterior margin of the wing vibrated equally above and below the line formed by the anterior margin, much of its elevating and propelling power would be sacrificed. The tail of the fish oscillates on either side of a given line, but it is otherwise with the wing of a flying animal. The fish is of nearly the same specific gravity as the water, so that the tail, as a rule, only propels. The flying animal, on the other hand, is very much heavier than the air, so that the wing requires both to propel and *elevate.* The wing to be effective as an *elevating organ* must consequently be vibrated rather below than above the centre of gravity; at all events, the intensity of the vibration should occur rather below that point. In making this statement, it is necessary to bear in mind that the centre of gravity is *ever varying,* the body rising and falling in a series of curves as the wings ascend and descend.

To *elevate* and *propel,* the posterior margin of the wing must rotate round the anterior one, the posterior margin being, as a rule, always on a lower level than the anterior one (*vide* pages 414, 415, and 416). By the oblique and more vigorous play of the wings *under* rather than *above* the body, each wing expends its entire energy in pushing the body *upwards* and *forwards.* Fig. 12, page 342, will illustrate my meaning. Let the oar *x, s,* represent the wing. If the wing

be made to play equally above (*a b*) and below (*c d*) the body, the tendency is to drive the body in an *undulating line*, away from *x*, in the direction *s x*. As, however, the opposite wing tends to push the body in a precisely contrary direction, the forces exercised by the two wings neutralise each other in the mesial line of the bird, the force which ultimately prevails being that of gravity. To destroy the power of gravity, and to elevate and propel the bird, it is necessary that the wings descend further than they ascend, and that the posterior margins of the wings be constantly kept on a lower level than the anterior ones. It is also necessary that the wings be *convex* on their upper surfaces, and *concave* on their under ones, and that the concave or biting surfaces be brought more violently in contact with the air during the down stroke, than the convex ones during the up stroke. The greater range of the wing below than above the body, and of the posterior margin below than above a given line, may be readily made out by watching the flight of the larger birds. It is also well seen in the upward flight of the lark. The range of the wing of the gull in ordinary flight is shown at Plate XIV. fig. 19. When the wing is elevated high above the body, as represented at 3 of figures 5 and 18, Plates XI. and XIV., it is generally in the effort of rising, or in picking up garbage from the surface of the sea, or in suspending or letting the body down gradually prior to alighting. In such cases the wings expend their greatest force when a little above or on a level with the body, as is well exemplified in the hovering of the kestrel.

Compound Rotation of the Wing of the Bird.—To work the tip and posterior margin of the wing independently and yet simultaneously, two axes are necessary, one axis (the short axis) corresponding to the root of the wing; the second (the long axis) to the anterior margin. This renders the wing eccentric in its nature. The primary or rowing feathers are also eccentric, the shaft of each feather being placed nearer the anterior than the posterior margin, an arrangement which enables the feathers to open up and separate during the up stroke, and approximate and close during the down one. The axes of rotation in the wing of the bird are given at figure 19, Plate XIV., *a* representing the short axis around which the tip of the wing rotates with a radius *e b f*; *c*, the long axis, around which the posterior margin of the wing revolves with a radius *g d h*.

These points are more fully illustrated at figure 45, p. 376, where *a b* represents the short axis (root of wing), with a radius *e f*; *e d*, the long axis (anterior margin of wing), with a radius *g p*.

The Wing of the Bird cranked slightly Forwards—the Compound Rotation of the Rowing Feathers.—It will be observed from figure 45 (p. 376), that the wing is cranked somewhat forwards (compare position of axis *a b* with that of axis *c d*), a very slight movement of rotation along the anterior margin (*c d*) being accompanied by a considerable rotation of the posterior margin (*h i j k l*). This figure also shows that the individual primary, secondary, and tertiary feathers

of the bird's wing have each what is equivalent to a long and a short axis. Thus the primary and secondary feathers marked *h i j*, *k l* are capable of rotating on their long axes (*r s*) and upon their short axes (*m n*). The feathers rotate upon

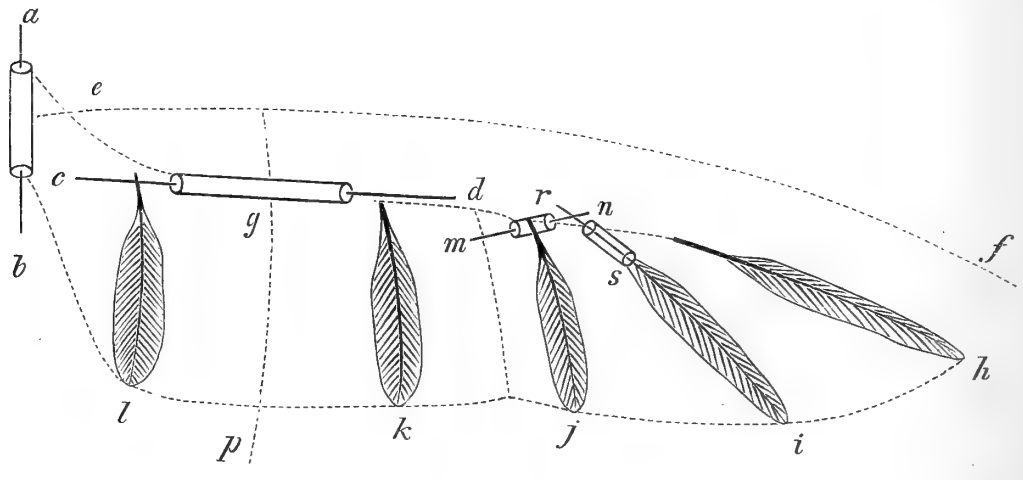


Fig. 45.

their long axes in a direction from below upwards during the down stroke, to make the wing impervious to air; and from above downwards during the up stroke, to enable the air to pass through it. The primary, secondary, and tertiary feathers have thus a distinctly valvular action.* They rotate upon their short axes (*m n*) during the descent and ascent of the wing, the tips of the feathers rising slightly during the descent of the pinion and falling during its ascent.

The Primary, Secondary, and Tertiary Feathers are Geared to each other, and Act in Concert.—To admit of the primary, secondary, and tertiary feathers rotating upon their long axes (*r s*), a very elaborate combination of fibrous and elastic structures, with a certain admixture of muscular substance, is necessary. The arrangement, as witnessed in the crested crane, is given at Plate XVI. figures 24, 25, 26, 27, and 28.

The roots of the primary, secondary, and tertiary feathers are imbedded behind the muscular mass (*f, f, h*), fig. 24, Plate XVI. The insertions of the roots of the feathers are shown in figure 28, Plate XVI. Each root is enveloped by a continuous elastic ligament (*o p q* of fig. 24), this ligament being provided with fibrous bands, which run in the direction of the length of the wing (*r s, t u, v w* of figs. 25 and 27, Plate XVI.) and obliquely (*g h, g h*). Two oblique bands (*g* and *h*) run between every two feathers (*x*), and are joined to the longitudinal ones (*rs tu vw*), and to the feathers in such a manner that the whole are geared together, an arrangement combining great freedom of movement with great strength. The longitudinal bands run along the roots of all the feathers, and

* The valve action, as explained, is called more or less into play according to circumstances.

are three in number, the outermost band breaking up at the root of each feather, and giving off two processes (*a d*, *b e*, *c f* of figure 25, Plate XVI.), the one of which coils round the root of the feather in a spiral manner from right to left; the other coiling in an opposite direction, or from left to right (*m*, *n* of figure 26, Plate XVI.) The root of each feather is consequently enveloped by a fibrous investment, capable of rotating it in opposite directions. The fibrous bands referred to are arranged with much precision, and as they are geared to each other at stated intervals, they cause the feathers (right wing) to rotate at nearly the same instant from right to left, and from below upwards, during extension; and from left to right, and from above downwards, during flexion. The arrangement of the fibrous bands is much the same on the dorsal and ventral aspects of the wing (compare figs. 24 and 28). It varies slightly in different species of birds, but the function of the bands is the same in all.

The tips of the primary, secondary, and tertiary feathers are prevented from rising too high during the descent of the wing by the oblique overlapping of the feathers forming the primary, secondary, and tertiary coverts (*m*, *n*, *o* of figure 28, Plate XVI.), those feathers acting as buffers and limiting the action.

The Up or Return Stroke of the Wing of the Bird—Diminution of Area of Wing—Valvular Action, &c.—Towards the termination of the down stroke, the wing is suddenly flexed and drawn towards the body, as shown at 4, 5, 6 of figures 6 and 19, Plates XI. and XIV. This is necessary to convert the wing from a long (Plate XI. figure 6, *c d*) into a short lever (Plate XI. figure 6, *a b*), and to destroy the momentum acquired by the wing during its more or less vertical descent. While the wing is being shortened, the angles which the several portions of its under surface make with the horizon are being diminished (*c d e f* of figures 16 and 17, page 349); the angles made by the under surfaces of the rowing feathers from within outwards being increased (1 2 3 4 5 6 7 8 9 of fig. 46, p. 378). These changes prepare the wing of the bird for making an effective up or return stroke, and are necessitated by the more vertical play of the bird's wing, as compared with that of the insect. But for the diminution of the actual area of the wing during the up stroke, the upper or dorsal surface of the pinion would experience much resistance from the air during its ascent. This difficulty is in a great measure obviated by the wing being drawn close to the side of the body, and by its being made to assume a somewhat crippled appearance, the tip of the wing folding upon the root in a direction from below upwards, and in such a manner as to displace comparatively little air (*vide* 4, 5, 6 of figure 6, Plate XI.) The pinion is then, as a rule, elevated as a short lever (*a b* of figure 6, Plate XI.), until it attains the position indicated at 1 of figures 5 and 18, Plates XI. and XIV. In these situations the wing is for the most part deeply arched (*vide* figure 13, Plate XIII.) When the wing has assumed the position indicated by 1 of

figures 5 and 18, Plates XI. and XIV., it is suddenly pushed away from the body, extended and elevated, as shown at 2 and 3 of the same figures; the angles made by the several portions of its under surface with the horizon being increased, while those formed by the under surfaces of the rowing feathers are decreased (1 2 3 4 5 6 7 8 9 of fig. 47). The wing thus comes to form a kind of natural parachute, as shown at 2, 2′ and 3, 3′ of figure 18, Plate XIV. This completes the up or return stroke. While the wing is ascending, the primary, secondary, and tertiary feathers rotate upon their long axes, and present their thin margins to the air, into which they cut like so many knives. The feathers are most widely separated at the beginning of the up stroke, and least at the termination of that act, as they then flap together to make the wing impervious, and prepare it for making the down stroke. The individual primary, secondary, and tertiary feathers are so arranged and so rotated that they open up, and close, and present the precise angles required for flight, whatever the shape and whatever the position of the wing.

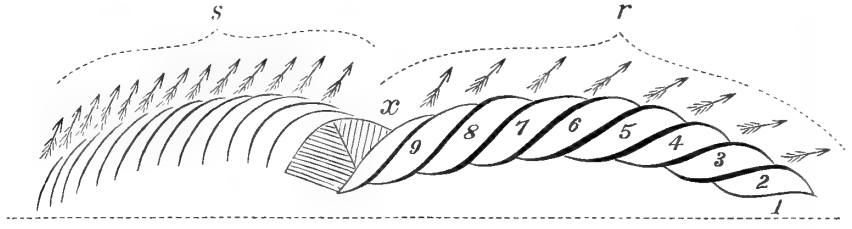


Fig. 46.

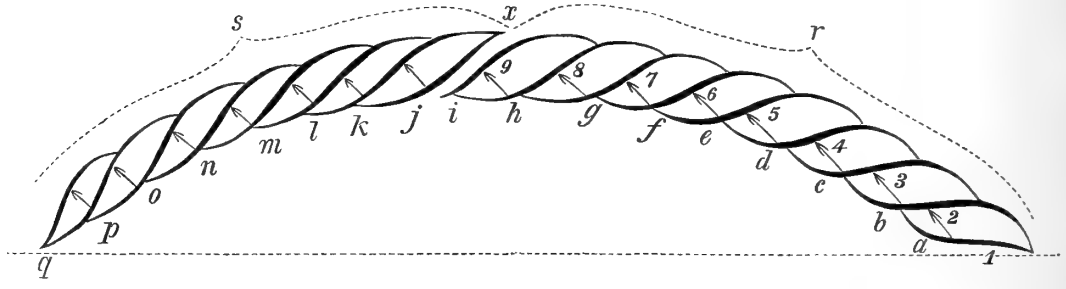


Fig. 47.

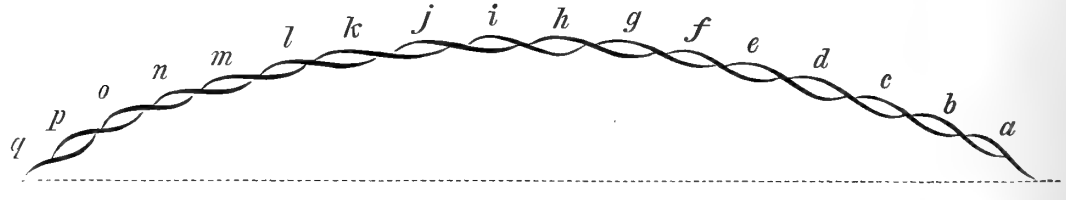


Fig. 48.

Figure 46 shows the tips of the primary (*r*) and secondary (*s*) feathers in the wing of the piet during flexion, and it will be observed that the angles made

by the rowing feathers with the horizon (see straight dotted line) in a direction from within outwards is greater than those made by the same feathers (*r*), in extension, as represented at figure 47. In figure 46 the wing is folded upon itself at *x*, and presents two arches, a larger (*r*) and a smaller (*s*), the numbers 1 2 3 4 5 6 7 8 9 giving the position of the primary feathers when counted from without inwards, the arrows indicating the direction in which the primary and secondary feathers open up and cut into the air from below upwards and from within outwards during the up stroke. This figure shows that the primary and secondary feathers (particularly the former), when viewed from the tip, or when cut across, present a spiral contour (*c g* of figure 49). This arises from the primary and secondary feathers being twisted upon themselves, as represented at *a b*, *c d* of figure 50.

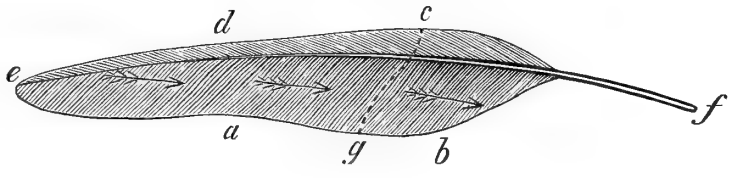


Fig. 49. Primary Feather, showing double curves at anterior margin (*c d*), posterior margin (*a b*), and across (*c f*).

Fig. 50. The same, seen from before edgeways. Here the anterior (*c d*) and posterior (*a b*) margins cross each other.

Figure 47 shows that the primary and secondary feathers of the wing of the piet are thrown into a beautiful groined arch in extension, preparatory to the down stroke, the advantage in favour of a concave surface over a convex one for seizing air or water being something like 2 to 1. It also shows that the primary (*r*) and secondary (*s*) feathers in extension, and during the down stroke, rotate upon their long axes in a direction from below upwards, as indicated by the arrows *a b c d e f g h i j k l m n o p q*, so as to form an arch which cannot be destroyed so long as the individual feathers remain intact. In fact, the integral parts of the arch are so disposed that the greater the pressure the greater the strength. Figure 48 shows a similar groined arch formed by the roots of the primary and secondary feathers, the spirals constituting the arch (*a b c d e f g h i j k l m n o p q*) running in an opposite direction to those seen in figure 47, from the fact of the primary and secondary feathers being twisted upon themselves as already explained (compare *b c* with *a d* of figure 50). Fig. 20, Plate XIV. shows how the air is forced during the down stroke in a spiral direction (*vide* arrows) from without inwards,

from before backwards, and from above downwards, the spiral currents from the two wings impinging upon the sides of the bird, which is wedge shaped, in such a manner as to force it upwards and forwards. The currents also cross and neutralise each other below the body of the bird, and thus supply additional buoyancy and propelling power. The arch made by the wing of the gull, when fully extended and ready to give the down stroke, is seen at 3, 3′ of figure 18, Plate XIV.; that made at the middle of the down stroke at figure 15, Plate XIII.; and that made at the end of the down stroke at figure 13, Plate XIII. The arch made by the wing of the gannet in extreme extension is shown at figure 16, Plate XIII.

The Primary, Secondary, and Tertiary Feathers Imbricate or Overlap.—Another point of interest in the bird's wing is the manner in which the various feathers (primary, secondary, and tertiary) overlap (fig. 20, Plate XIV.), and the varying degrees of strength which they exhibit. Proceeding from the tip of the wing towards the root we find as a rule that the first three primary feathers are longer and stronger and overlap more than the second three—the second three being longer, stronger, and overlapping more than the third three. These points are well seen in the acuminate scythe-like wing, of which that of the gull (fig. 15, Plate XIII.) and gannet (fig. 16, Plate XIII.) are good examples.* Similar remarks may be made of the secondary and tertiary feathers, as a reference to *p q* of fig. 16, Plate XIII., will show. Another not less interesting feature is the varying position of the vanes of the primary, secondary, and tertiary feathers. Thus, in the first primary the vane (*e f* of fig. 49, page 379), is placed quite on the anterior margin (*c d*) the posterior margin (*a b*) being three or four times broader than the anterior one to admit of overlapping. The vane of the feather occupies a more and more central position as we proceed from the tip in the direction of the root of the wing, as shown at *h i j k l* of fig. 45, page 376, and also at 1, 2, 3, 4, 5, 6, 7, 8, 9, *j k l m n*, &c., of fig. 20, Plate XIV. The first primary, as will be seen from this account, is eccentric in its nature. It is more eccentric than the second—the second being more eccentric than the third, and so of all the primary and secondary feathers, until the stem of the feather is found to occupy its centre. The posterior margin of the first primary, as a consequence, rotates more than that of the second—the second than the third, and so of the others—the valvular action of the wing being most marked at the tip of the pinion, and gradually diminishing in the direction of the root. The rowing feathers are necessarily eccentric. If the axis of each feather was not placed nearer the anterior than the posterior margin the anterior margin would rise as much as the posterior margin is depressed. This, however, is prevented

* In some cases, as for instance in the more rounded form of wing shown in fig. 20, Plate XIV., the 4th, 5th, and 6th primaries are longer and stronger, and overlap more than the 1st, 2d, and 3d.

by the axis of the feather occupying an anterior position, the feather when it is made to rotate causing the posterior margin (because of its greater breadth) to move through a greater arc of a circle than the anterior margin. It is owing to the greater travel of the posterior margin as compared with the anterior one, that the feathers of the wing so readily open in flexion and close in extension. The gradation in the length, and strength, and in the degree of overlapping is necessitated by the fact that the feathers at the tip of the wing are exposed to a much greater strain than those nearer the root—the former always travelling through a much greater space in a given time than the latter.

The Wing of the Bird not always Opened Up to the same extent in the Up Stroke.—The elaborate arrangements and adaptations just referred to for increasing the area of the wing, and making it impervious to air during the down stroke, and for decreasing the area and opening up the wing during the up stroke, although necessary to the flight of the heavy-bodied, short-winged birds, as the grouse, partridge, and pheasant, are by no means indispensable to the flight of the long-winged oceanic birds, unless when in the act of rising from a level surface; neither do the short-winged heavy birds require to fold and open up the wing during the up stroke to the same extent in all cases, less folding and opening up being required when the birds fly against a breeze, and when they have got fairly under weigh. All the oceanic birds, even the albatros, require to fold and flap their wings vigorously when they rise from the surface of the water. When, however, they have acquired a certain degree of momentum, and are travelling at a tolerable horizontal speed, they can in a great measure dispense with the opening up of the wing during the up stroke—nay, more, they can in many instances dispense even with flapping. This is particularly the case with the albatros, which (if a tolerably stiff breeze be blowing) can sail about for an hour at a time without once flapping its wings. In this case the wing is wielded in one piece like the insect wing, the bird simply screwing and unscrewing the pinion on and off the wind, and exercising a restraining influence—the breeze doing the principal part of the work. In the bat the wing is jointed as in the bird, and folded during the up stroke. As, however, the bat's wing, as has been already stated, is covered by a continuous and more or less elastic membrane, it follows that it cannot be opened up to admit of the air passing through it during the up stroke. Flight in the bat is therefore secured by alternately diminishing and increasing the area of the wing during the up and down strokes—the wing rotating upon its root and along its anterior margin during its ascent and descent precisely as in the bird.

Analysis of the Movements of Extension and Flexion in the Wing of the Gannet.—The changes which the wing undergoes in extension and flexion are seen to great advantage in the gannet (figs. 9, 10, and 11, Pate XII.)

The pinion of this bird is remarkable for its great length as compared with

its breadth, and for the general elegance of its shape (*vide* figs. 11 and 16, Plates XII. and XIII.) It is especially interesting from the fact that the wing movements can be more readily and satisfactorily analysed by its aid than by the aid of any other British wing with which I am acquainted. The following account, taken from a perfectly fresh specimen, may prove interesting.

The joints of the gannet's wing, particularly the shoulder joint (*x* of figs. 16 and 17, Plate XIII.) admit of very free movements. When the wing is slightly flexed the under surface of the posterior margin of the pinion can be rotated downwards and forwards until it makes a right angle with the horizon—the greatest angle which it makes in extension amounting to something like 45°. In flexion the elbow (*s* of figs. 9, 10, and 11, Plate XII.), wrist (*t*), and metacarpal joints (*v w*) admit of a great variety of movements, the forearm (*c d*) moving on the arm (*e f*), and the hand (*a b*) upon the forearm (*c d*) in an oblique spiral direction from above downwards and from below upwards. The whole pinion, in fact, is flaccid, and the feathers opened up and thrown out of position as shown more especially at figs. 9 and 10, Plate XII. The forearm is folded upon the arm in nearly the same plane (*vide x s t* of fig. 17, Plate XIII.), the secondary and tertiary feathers (*c e g* of fig. 9, Plate XII.) being inclined slightly upwards and forwards, so that they form inclined surfaces with the horizon —the secondaries forming an inclined surface which looks inwards and upwards as indicated by the arrow marked *c d* of fig. 9, Plate XII., the tertiary feathers forming two inclined surfaces, one of which is directed upwards and outwards as indicated by the arrow *e f* of fig. 9, Plate XII., the other inclining upwards and inwards as shown at *g h* of fig. 9, Plate XII. The hand rotates upon the wrist (*t* of fig. 9, Plate XII.,) as upon a hinge, the tip of the wing as it darts out and in describing the segment of a circle (*m n* of fig. 9, Plate XII.) The hand is folded upon the forearm in such a manner that the anterior margin of the tip of the wing (*v w b* of fig. 9, Plate XII.) ascends, while the posterior margin (*a* of fig. 9, Plate XII.) descends. As a consequence the hand and tip of the wing are folded beneath the forearm or body of the wing as indicated by the radius *m n* of fig. 9, Plate XII. The hand and tip of the wing form with the horizon an inclined surface, which is directed *outwards* and *upwards* as indicated by the arrows *a b* of fig. 9, Plate XII. The *upward* and *outward inclination* of the under surface of the outer portion of the wing of the gull is well seen at *a b* of fig. 12, Plate XII. The tip of the wing, it will be observed, acts during flexion as a true kite from *below upwards* and from *within outwards*.* We have in the flexed wing of the gannet four different sets of

* The same happens in the wings of all birds, and in the wing of the bat and insect. The outward and upward inclination of the tip of the wing is well seen in the beetle. This portion of the wing acts as a true kite, when the wing is being extended or thrust away from the body towards the termination of the up stroke. The under surface of the tip of the wing consequently contributes to flight during the up stroke.

inclined surfaces, two directed upwards and *outwards*, viz., *e f* and *a b* of fig. 9, Plate XII., and two directed upwards and *inwards*, viz., *c d* and *g h* of fig. 9, Plate XII. Those surfaces when the wing is moving are ever varying, and cause the different portions of the pinion to act like so many kites. Thus, during extension, the two portions of the wing marked *a b* and *e f* (fig. 9, Plate XII.,) fly outwards and upwards, the two portions marked *c d* and *g h* (fig. 9, Plate XII.,) flying inwards and upwards during flexion. As the two portions of the wing, marked *a b* and *e f*, draw a current after them during extension, on which the two portions marked *c d* and *g h* operate during flexion, it follows that one part of the wing, whatever its position in space, makes a current on which another portion inevitably acts. This result is facilitated by the manner in which the primary and secondary feathers rotate upon their long axes in flexion and extension, and also by the ascent and descent of the wing, inasmuch as flexion always occurs towards the end of the down stroke, and extension towards the end of the up stroke. The wing, I may add, as a rule produces a current during the up stroke on which it operates during the down stroke and *vice versa*. The inclined surfaces represented at fig. 9, Plate XII., are reproduced in the partly extended wing at fig. 10, Plate XII., and a comparison of the arrows marked by the same letters in the two figures will show that the angles of inclination formed by the surfaces in question are somewhat changed. The wing when fully extended is seen at fig. 11, Plate XII. Complete extension is followed by the obliteration of the inclined surfaces indicated by the arrows *a b, e f, c d, g h* of figs. 9 and 10, Plate XII. The obliteration of the inclined surfaces *a b, e f, c d, g h* of figs. 9 and 10, Plate XII., is followed by the production of other inclined surfaces, these being occasioned by the rotation of the wing upon its anterior margin (long axis) towards the termination of extension. The angles of inclination formed by the under surface of the wing in the extended condition are greatest towards the root and least towards the tip of the wing, as shown at *q p o* of fig. 16, Plate XIII. When the gannet's wing is extended and flexed by the aid of the hand, as represented at figs. 16 and 17, Plate XIII., it shows the screwing and unscrewing action of the pinion to perfection ; the dorsal and ventral surfaces of the wing oscillating on either side of a given line—the dorsal surface appearing above the line in flexion (figs. 17, Plate XIII.,) and the ventral surface under the line in extension (fig. 16, Plate XIII.) The upward and downward screwing of the wing in flexion and extension is also shown at fig. 8, Plate XII.—the wing to the right of the observer being flexed, and having its anterior margin (*d e f*) directed slightly downwards (*vide* arrow), the wing to the left being extended, and having its anterior margin (*d′ e′ f′*) directed decidedly upwards (*vide* arrow.)

The Angles of Inclination which the Under Surface of the Gannet's Wing makes with the Horizon in Extension and Flexion vary.—When the wing of the

gannet is extended the angle which its under surface makes with the horizon, especially the portion opposite the elbow joint (*q* of fig. 16, Plate XIII.), is much greater than one would anticipate—indeed, it is little short of 45°. The tip of the wing (*o p* of fig. 16, Plate XIII.,) does not, however, make an angle of more than 25° or 30°. This is a most interesting point, as it shows that the different portions of the wing in extension make different angles with the horizon—that made by the tip of the wing being the least, and that made by the root of the wing the greatest. The inclined surfaces are no doubt adapted to suit the travel of the wing, and to produce a uniform result as far as buoyancy is concerned. Thus the wing acts with a gradually decreasing angle from the root towards the tip—the speed of the wing increasing in the direction of its extremity. This is important, as a surface with a small angle travelling at a high speed supplies the same amount of buoying power as a surface with a greater angle moving at a lower speed. Indeed, on making a careful examination of the gannet's wing I have had no difficulty in determining that the different parts of the wing not only make various angles of inclination with the horizon in an antero-posterior direction at every stage of extension flexion in the down and up strokes, but that they also make various angles of inclination with the horizon in a direction from within outwards. In other words, I find that in extension the wing attacks the air from behind forwards and from within outwards at one and the same instant—the different parts of the pinion tacking upon the air kite fashion, precisely as a sailing vessel would. The same thing happens in the wing of the insect. Here, as I have already pointed out, the posterior margin twists upon and partially rotates round the anterior margin, so as to convert the wing into a screw which moves in all its parts. This twisting and untwisting has the effect of alternately producing a surface which attacks the air (at various angles of inclination) from within outwards, and from behind forwards, and from without inwards and from before backwards. Curiously enough, the inclined surfaces formed by the different portions of the insect's wing with the horizon vary to accommodate themselves to the velocity acquired by its different parts—the surfaces being least inclined where the speed is highest, and *vice versa*. This, therefore, is a fundamental point in the construction and application of all wings, and affords the only rational solution of the involved problem of flight. The various angles of inclination made by the wing with the horizon from within outwards and the reverse, and from behind forwards and the reverse, are all necessary to produce a perfect buoyancy.

When the wing of the gannet is fully extended it is also rendered more or less rigid. The joints, however, even the metacarpal ones, are free to move, which shows that the wing, to be effective during the down stroke, must be thoroughly under the control of the muscular and ligamentary system. This is all the more necessary, as the roots of the primary and secondary feathers

have an inclination to move in an upward direction, and require to be restrained.

After carefully analysing the movements of the gannet's wing in the dead bird, I felt deeply impressed with the necessity of studying the same movements in the living one. I therefore made an excursion to the Bass Rock (North Berwick, Scotland) for this purpose, in July 1870. It was breeding season, and the birds were in myriads, and so tame that they wheeled around and above me at distances, in some cases, not exceeding from six to eight yards. The gannets which were hatching permitted me to approach within a yard of them, and required to be driven from their nests by the aid of a stick. I had, therefore, every facility for analysing the flight of this the most cherished and beautiful of the British birds. Before proceeding to describe the results of the expedition in question I may state, briefly, the measurement, weight, &c., of the gannet, the movements of whose wings I have just recorded. For the sake of comparison I will also give the weight and measurements of a heron—this bird differing widely from the gannet in the configuration of its wings.

Measurement, Weight, &c., of Gannet and Heron.—The following details of weight, measurement, &c., of the gannet were supplied by an adult specimen which I dissected during the winter of 1869. Entire weight, 7 lbs. (minus 3 ounces); length of body from tip of bill to tip of tail, 3 feet 4 inches; head and neck, 1 foot 3 inches; tail, 12 inches; trunk, 13 inches; girth of trunk, 18 inches; expanse of wing from tip to tip across body, 6 feet; widest portion of wing across primary feathers, 6 inches; across secondaries, 7 inches; across tertiaries, 8 inches. Each wing, when carefully measured and squared, gave an area of $19\frac{1}{2}$ square inches. The wings of the gannet, therefore, furnish a supporting area of 3 feet 3 inches square. As the bird weighs close upon 7 lbs., this gives something like 13 square inches of wing for every $36\frac{1}{3}$ ounces of body, *i.e.*, 1 foot 1 square inch of wing for every 2 lbs. $4\frac{1}{3}$ ounces of body.

The heron, a specimen of which I dissected at the same time, gave a very different result, as the subjoined particulars will show. Weight of body, 3 lbs. 3 ounces; length of body from tip of bill to tip of tail, 3 feet 4 inches; head and neck, 2 feet; tail, 7 inches; trunk, 9 inches; girth of body, 12 inches; expanse of wing from tip to tip across the body, 5 feet 9 inches; widest portion of wing across primary and tertiary feathers, 11 inches; across secondary feathers, 12 inches.

Each wing, when carefully measured and squared, gave an area of 26 square inches. The wings of the heron, consequently, furnish a supporting area of 4 feet 4 inches square. As the bird only weighs 3 lbs. 3 ounces, this gives something like 26 square inches of wing for every $25\frac{1}{2}$ ounces of bird, or 1 foot $5\frac{1}{4}$ inches square of wing for every 1 lb. 1 ounce of body.

In the gannet there is only 1 foot 1 square inch of wing for every 2 lbs. $4\frac{1}{3}$ ounces of body. The gannet has, consequently, less than half of the wing area of the heron. The gannet's wing is, however, a long narrow wing (that of the heron is broad), extended transversely across the body in the direction of its length; and this is found to be the most powerful form of wing—the wings of the albatros, which measure 14 feet from tip to tip (and only one foot across), elevating 18 lbs. without difficulty. If the wings of the gannet, which have a superficial area of 3 feet 3 inches square, are capable of elevating 7 lbs., while the wings of the heron, which have a superficial area of 4 feet 4 inches, can only elevate 3 lbs., it is evident (seeing the wings of both are twisted levers, and formed upon a common type) that the gannet's wing must be vibrated with greater energy than the heron's wing; and this is actually the case. The heron's wing, as I have stated (foot note to page 392), makes 60 down and 60 up strokes every minute; whereas the wing of the gannet, when the bird is flying in a straight line to or from its fishing ground, makes close upon 150 up and 150 down strokes during the same period. The wings of the divers and other short-winged, heavy-bodied birds are urged at a much higher speed, so that a comparatively small wing can be made to elevate a comparatively heavy body, if the speed with which the wing is driven only be increased sufficiently.* Flight, therefore, is a question of power, speed, and small surfaces *versus* weight. While there is apparently no fixed relation between the area of the wing and the animal to be raised, there is (unless in the case of sailing birds, which have acquired momentum) an unvarying relation as to the weight to be elevated and the number of oscillations; so that the problem of flight would seem to resolve itself into one of weight, power, velocity, and small surfaces, as against comparative levity, debility, diminished speed, and extensive surfaces.† Elaborate measurements of wing area and minute calculations of speed can, consequently, only determine the minimum of wing for elevating the maximum of weight—flight being attainable within a comparatively wide range. That the superficies of the wings destined to carry a certain weight may, and does vary, is proved by the fact that large portions of the wings of insects and birds, as I have pointed out,‡ may be removed without destroying or even impairing the function of flight. In such cases the speed with which the wings are driven is increased in the direct ratio of the mutilation. It is further proved by the ingenious researches of M. DE LUCY, who has shown, by careful measurements, that the

* The grebes among birds and the beetles among insects furnish examples where small wings, made to vibrate at high speeds, are capable of elevating great weights.

† "On the Mechanism of Flight," by the Author, Trans. Linn. Soc., vol. xxvi. page 219.

‡ *Vide* page 326 and foot-note to pages 361 and 362 of the present memoir, and pages 219, 220, 221, and 222 of my memoir "On the Mechanical Appliances by which Flight is Attained in the Animal Kingdom," Trans. Linn. Society, vol. xxvi.

area of the wings decreases as the size and weight of the body increase. M. DE LUCY has tabulated his results, which I subjoin.*

INSECTS.		BIRDS.	
Names.	Referred to the kilogramme. =2 lbs. 8 oz. 3 dwt. 2 gr. Avoird. =2 lbs. 3 oz. 4·428 dr.	Names.	Referred to the kilogramme.
	sq. yds. ft. in.		sq. yds. ft. inch.
Gnat, ...	11 8 92	Swallow, ...	1 1 $104\frac{1}{2}$
Dragon-fly (small), . . .	7 2 56	Sparrow, ...	0 5 $142\frac{1}{2}$
Coccinella (Lady-bird), . .	5 13 87	Turtle dove, ...	0 4 $100\frac{1}{2}$
Dragon-fly (common), . .	5 2 89	Pigeon, ...	0 2 113
Tipula, or Daddy-long-legs, .	3 5 11	Stork, ...	0 2 20
Bee, ...	1 2 $74\frac{1}{2}$	Vulture, ...	0 1 116
Meat-fly, ...	1 3 $54\frac{1}{2}$	Crane of Australia, . . .	0 0 139
Drone (blue), ...	1 2 20		
Cockchafer, ...	1 2 50		
Lucanus cervus (Stag-beetle (female),	1 1 $39\frac{1}{2}$		
Stag-beetle (male),	0 8 33		
Rhinoceros-beetle, ...	0 6 $122\frac{1}{2}$		

"It is easy, by the aid of this table, to follow the order, always decreasing, of the surfaces, in proportion as the winged animal increases in size and weight. Thus, in comparing the insects with one another, we find that the gnat, which weighs 460 times less than the stag-beetle, has 14 times more of surface. The lady-bird weighs 150 times less than the stag-beetle, and possesses 5 times more of surface, &c. It is the same with the birds. The sparrow weighs about 10 times less than the pigeon, and has twice as much surface. The pigeon weighs about 8 times less than the stork, and has twice as much surface. The sparrow weighs 339 times less than the Australian crane, and possesses 7 times more surface, &c. If now we compare the insects and the birds, the gradation will become even much more striking. The gnat, for example, weighs 97,000 times less than the pigeon, and has 40 times more surface; it weighs three millions of times less than the crane of Australia, and possesses 140 times more of surface than this latter, the weight of which is about 9 kilogrammes 500 grammes (25 lbs. 5 oz. 9 dwt. troy, 20 lbs. 15 oz. $2\frac{1}{4}$ dr. avoirdupois.

"The Australian crane is the heaviest bird that I have weighed. It is that which has the smallest amount of surface, for, referred to the kilogramme, it does not give us a surface of more than 899 square centimetres (139 square inches), that is to say, about an eleventh part of a square metre. But every one

* "On the Flight of Birds, of Bats, and of Insects, in reference to the subject of Aërial Locomotion," by M. DE LUCY, Paris.

knows that these Grallatorial animals are excellent birds of flight. Of all travelling birds they undertake the longest and most remote journeys. They are, in addition, the eagle excepted, the birds which elevate themselves the highest, and the flight of which is the longest maintained."

Flight of Gannet as witnessed at the Bass Rock.—But to return to the gannet, the flight of which, as witnessed from the Bass, I was about to describe.

The wings and body of the bird, as I fully satisfied myself, can be moved in all their parts. The wings and body are, moreover, thoroughly under control. The body can be twisted about in a remarkable manner—sideways and in an upward and downward direction. The individual feathers of the wing are likewise under control. In fact, the muscular movements can be seen extending along the pinion to the roots of the rowing feathers, the muscular influence spreading thence to the tips. This could readily be ascertained, as the birds wheeled round and round right overhead, and within a very few yards of where I was standing.

When the gannet throws itself from a cliff it makes a large curve, the convexity of which is directed downwards. It acquires speed and momentum by a few gentle flappings of the wings, or it holds the wings comparatively motionless, and sails for a great distance without effort—the weight of the trunk doing the principal portion of the work.* In the sailing movement the body is forced into an upward or downward curve, according to circumstances.

When the bird has acquired momentum, either by flapping its wings or by projecting itself from a cliff, it has the air perfectly under control. If it wishes to turn to the right it elevates the left wing and depresses the right one, the head and neck bending in the direction of the curve to be described. If it would turn to the left the movements are reversed.† If it desires to ascend, the head, neck, body, and wings are elevated in an upward direction, so as to increase the angle made by them with the horizon, the angle referred to being decreased or reversed when the bird wishes to descend. If the bird aims at horizontal flight, the head, neck, body, and wings are arranged so as to be nearly parallel with the surface of the sea. The gannet wheels and skims about with all imaginable ease and grace—now oscillating on the long axis of the body as a centre, and now upon the long axes of the wings as a centre. In all these movements the head, neck, tail, and body perform an important part.

When the gannet throws itself from a rock it rises to nearly the same level as that from which it precipitated itself, without any apparent effort, thus showing that the friction experienced in flight must be almost *nil*.

The neck, body, and tail, of the gannet are exceedingly flexible, and admit

* Compare with mechanical experiment described at pages 355 and 356.

† The swallow and crane, which dart along at a very high speed, tilt their bodies in turning; but, in addition, flap their wings and fly round the curve they wish to describe.

of being curved in every direction. The feet are extended straight out behind the bird, and appear on the under surface of the tail. The body forms an elongated and very graceful ellipse, admirably adapted for cleaving the air and eluding resistance.

When the gannet propels itself by the more or less vertical flappings of its wings, the angles which the under surfaces of the wings and body make with the horizon are very considerable—something like 25° or 30°. Of this I convinced myself in a variety of ways.* When the bird has acquired speed and momentum, and begins to sail, the angle made by the under surfaces of the body and wings is reduced according to circumstances, and in some instances nearly obliterated, the bird gliding along for long distances with its body and wings apparently parallel to the surface of the ocean.

The wings of the gannet, when fully extended, are curved alternately forwards and backwards. Thus, the arm and hand are inclined backwards, and the forearm forwards. When the wings are flexed in ordinary flight the movement occurs principally at the wrist joint, the arm and forearm bending comparatively little, and affording a wide basis of support both during the down and up strokes. In forced flight in flexion the wing bends perceptibly at the elbow as well as the wrist, the wing during the up stroke forming a short lever, and being thrown into a fine arch, the convexity of which is directed upwards. The tip of the wing works out and in during the down and up strokes; and a close examination satisfied me that the bird has the power of forcing the posterior margin of its wings *into wave curves* while the wings are rising and falling, the air taking no part in the production of the waved movements.

The down stroke is delivered with perceptibly greater rapidity and energy than the up stroke. Of this there can be no doubt whatever. This allows the air, set in motion by the wing during its descent, time to re-act on the under surface of the pinion so as to contribute to its elevation. This result is facilitated by the wing striking very decidedly *downwards and forwards.*

When the gannet alights at its nest it delivers a few very energetic strokes at right angles to the direction of its flight, and thus slows itself.

When the gannet plunges into the sea from a height it tilts its body until it assumes a more or less perpendicular position, and descends with such impetuosity as to displace the water in an upward direction, until it attains an altitude of from 10 to 15 feet. It flies beneath the water with remarkable rapidity, and emerges without difficulty, the momentum acquired during the descent assisting it through and out of the water. In fact the gannet, when it stoops to pick up a fish, simply describes a continuous downward curve, part of the curve being

* In the dragon-fly the anterior pair of wings make a smaller angle with the horizon than the posterior pair. The first pair of wings are, consequently, more actively engaged as propellors—the second pair as elevators.

formed in the air and part in the water. Those movements, so numerous, varied, and beautiful, are all the result of volition. It is impossible to resist this conclusion after deliberate and careful watching.

A Regulating Power necessary in Flight.—That the wing is propelled for the most part by voluntary movements, may be ascertained in the following manner.

If the sentient nerve of a pigeon's wing be divided (the motor nerve being left intact) the bird flutters most energetically, but altogether fails to fly.* In this experiment neither the flexibility, elasticity, nor the power which the wing possesses of moving in all its parts, are tampered with. The guiding or controlling power alone is impaired.

That the wing is vibrated intelligently admits of direct proof. Thus if we hold a captured bird in the hand, we feel that it directs and controls the action of its wings in such a manner that a tractile force is produced, now in one direction now in another, in its efforts to escape; nay more, that the force after a brief fluttering is concentrated at that point where it is most loosely held, and which offers the greatest chance of escape.

Second, The wings of birds, as any one may readily ascertain by watching the flight of rooks, are visibly under control both during the down and up strokes. They are, moreover, deliberate leisurely movements. By leisurely movements, I mean such as are the result of design, and not such as would be produced by the sudden recoil of a merely elastic apparatus. Those who have watched, as I have frequently done, the rapid vibrations of natural and artificial wings, will readily understand the difference here indicated. In the living wing we have a smooth soft fanning continuous movement, quite devoid of dead points; whereas in artificial elastic wings, especially if worked vertically and without elastic bands at their roots, we have a wavering, jerking, irregular motion, particularly at the beginning of the up stroke.

Third, The blow-fly, as stated (p. 326), can fly with only one-third of its original wing area, the two-thirds which represent the more highly elastic portions of the wing being removed. In this case the wing is wielded intelligently figure of 8 fashion, the mutilation not interfering either with the freedom of motion enjoyed by the pinion at its root, or the power the insect possesses of directing and controlling the wing throughout its entire vibration.

There are therefore at least five separate items to be considered in flight, viz., intelligence and voluntary movements; secondly, mobility or the power which the wing possesses of moving its several parts; thirdly, the flexibility and elasticity of the wing; fourthly, the resistance and resiliency of the air upon which the wing operates; fifthly, the weight of the body of the flying animal, which may be regarded as an independent moving power.

* "Experiments practically demonstrating the laws by which birds fly," by Dr W. Smyth. Second Annual Report of the Aëronautical Society of Great Britain for 1867.

The wings of bats and birds are mobile because of their numerous joints (shoulder, elbow, wrist, meta carpal, &c.), and because of the muscles and fibro-elastic ligaments which operate upon these joints. They are also flexible and elastic, the one (the bat) because of its long, thin tapering fingers and enveloping membrane; the other (the bird) because of its tapering, primary, secondary, and tertiary feathers.

The insect wing is also mobile, the insect having the power not only of moving the pinion in various directions at its root, but of causing the movements generated at the roots to extend intelligently along the margins. The insect wing is flexible and elastic in the same sense that the wing of the bat and bird are flexible and elastic. The mobility, flexibility, and elasticity peculiar to the living wing is more intimately blended in the wing of the insect than in that of either the bat or bird. This arises from the fact that the wing of the insect is usually in one piece, and jointed only at its root.

The Wing at all times thoroughly under Control.—The advantage which the wing derives from being movable in all its parts, consists in this, that it can be wielded intelligently even to its extremity. This enables the insect, bat, and bird, to tread and rise upon the air as a master—to subjugate it in fact. The wing, no doubt, abstracts an upward and onward recoil from the air, but in doing this it exercises a selective and controlling power; it seizes one current, evades another, and creates a third; it feels and paws the air as a quadruped would feel and paw a treacherous yielding surface. It is not difficult to comprehend why this should be so. If the flying creature is living, endowed with volition, and capable of directing its own course, it is surely more reasonable to suppose that it transmits to its travelling surfaces the peculiar movements necessary to progression, than that those movements should be the result of impact from fortuitous currents which it has no means of regulating. That the bird requires to control the wing, and that the wing requires to be in a condition to obey the behests of the will of the bird, is pretty evident from the fact that most of our domestic fowls can fly for considerable distances when they are young and when their wings are flexible; whereas when they are old and the wings stiff, they either do not fly at all or only for short distances, and with great difficulty. This is particularly the case with tame swans. This remark also holds true of the steamer or race-horse duck (*Anas brachyptera*), the younger specimens of which only are volant. In the older birds the wings become too rigid and the bodies too heavy for flight. Who that has watched a sea-mew struggling bravely with the storm, could doubt for an instant that not only the wings but every individual feather of the wing was perfectly under control? The whole bird is an embodiment of animation and power. The intelligent active eye, the easy graceful oscillation of the head and neck, the folding or partial folding of one or both wings, nay more, the slight tremor or quiver of the individual

feathers of parts of the wings so rapid, that only an experienced eye can detect it, all confirm the belief that the living wing has not only the power of directing, controlling, and utilising natural currents, but of creating and utilising artificial ones, which is not less important. But for this power, what would enable the bat and bird to rise and fly in a calm, or steer their course in a gale? It is erroneous to suppose that anything is left to chance where living organisms are concerned, or that animals endowed with volition and travelling surfaces, should be denied the privilege of controlling the movements of those surfaces quite independently of the medium on or in which they are destined to operate. What would we say of that quadruped or that fish which depended for the major portion of its movements on the ground it trod or the water it navigated? I will never forget the gratification afforded me on one occasion at Carlow (Ireland) by the flight of a pair of magnificent swans. The birds flew towards and past me, and I had my attention directed to their presence by a peculiarly loud whistling noise made by their wings. They flew about fifteen yards from the ground, and as their pinions were urged not much faster than those of the heron,* I had abundant leisure for studying their movements. The sight was very imposing, and as novel as it was grand. I had never seen anything before, and certainly have seen nothing since that could in any way convey a more adequate idea of the prowess and guiding power which a bird may exert. What particularly struck me was the perfect mastery which they seemed to possess over everything. They had their wings and bodies visibly under control, and the air was attacked in a manner and with an energy which left little doubt in my mind that it played quite a subordinate part in the great problem before me. The necks of the birds were stretched out, and their bodies to a great extent rigid. They advanced with a steady stately motion, and swept past with a vigour and force which greatly impressed, and to a certain extent overawed, me at the time.† Their flight was what one could imagine that of a flying machine constructed in accordance with natural laws would be.

* I have frequently timed the beats of the wings of the common heron (*Ardea cinerea*) at Warren Point (Ireland). In March 1869 I was placed under unusually favourable circumstances for obtaining reliable results. I timed one bird high up over a lake for fifty seconds, and found that in that period it made fifty down and fifty up strokes; *i.e.*, one down and one up stroke per second. I timed another one in a heronry belonging to Major Hall. It was snowing at the time (March 1869), but the birds, notwithstanding the inclemency of the weather and the early time of the year, were actively engaged in hatching, and required to be driven from their nests on the top of the larch trees by knocking against the trunks thereof with large sticks. One unusually anxious mother refused to leave the immediate neighbourhood of the tree containing her tender charge, and circled round and round it right overhead. I timed this bird for ten seconds, and found that she made ten down and ten up strokes; *i.e.*, one down and one up stroke per second precisely as before. I have therefore no hesitation in affirming that the heron, in ordinary flight, makes exactly sixty down and sixty up strokes per minute. The heron, however, like all other birds when pursued or agitated, has the power of greatly augmenting the number of its beats.

† The above observation was made at Carlow on the Barrow in October 1867, and the account of it is abstracted from my note-book.

How the Wing is Attached to the Body—Movements of the Shoulder, Elbow, Wrist, and other Joints.—Having endeavoured to prove, in a variety of ways, that insects, bats, and birds have their wings thoroughly under control both during the down and up strokes, I now proceed to show that the configuration of the wing, its structure, its attachments to the body, its joints, its muscles (voluntary in their nature), and its elastic ligaments, many of which have muscular fibres running into them, all tend to confirm this belief.

While, however, saying so much, I take this opportunity of stating that the structure of the living wing and its relations and attachments to the body are such that if it moves at all it must move in such a manner as shall contribute to flight. In other words, the wing is mechanically perfect; and if it be made to vibrate, even by artificial means, all its movements will tend in the direction of flight. This, however, is a very different thing from asserting that the movements of the living wing are purely mechanical in their nature. By mechanical I mean such movements as would be produced by the elasticity of the wing and the reaction of the air, minus volition, minus the voluntary muscles—musculo-elastic ligaments and nerves of the wing. Flight is vito-mechanical in its nature and intelligence, or that form of action which results from *the habitual use* of intelligence, is necessary to its production.

All wings are constructed upon a common type. They are in every instance carefully graduated, the wing tapering from the root towards the tip, and from the anterior margin in the direction of the posterior margin. They are of a generally triangular form, and twisted upon themselves in the direction of their length, to form a helix or screw. They are convex above and concave below, and more or less flexible and elastic throughout, the elasticity being greatest at the tip and along the posterior margin. They are also movable in all their parts. In all the wings which I have examined, whether in the insect, bat, or bird, the wing is recovered, flexed, or drawn towards the body by the action of elastic ligaments, these structures, by their mere contraction, causing the wing, when fully extended and presenting its maximum of surface, to resume its position of rest and plane of least resistance. The principal effort required in flight is, therefore, made during extension and at the beginning of the down stroke. The elastic ligaments are variously formed, and the amount of contraction which they undergo is in all cases accurately adapted to the size and form of the wing and the rapidity with which it is worked, the contraction being greatest in the short-winged and heavy-bodied insects and birds, and least in the light-bodied and ample-winged ones, particularly in such as skim or glide. The mechanical action of the elastic ligaments, I need scarcely remark, ensures an additional period of repose to the wing at each stroke; and this is a point of some importance, as showing that the lengthened and laborious flights of insects and birds are not without their stated intervals of rest.

The twisting of the wing upon itself during its action, to which I have frequently directed attention, is occasioned in the bat and bird by the insertions and direction of the muscles—by the spiral configuration of the articular surfaces of the bones of the wing, and by the rotation of the bones of the arm, forearm, and hand upon their long axes. In the insect it is due to the insertions and direction of the muscles, and the conformation of the shoulder-joint, this being furnished with a system of check-ligaments, and with horny prominences or stops, set, as nearly as may be, at right angles to each other, and fashioned so as to necessitate the wing acting in the manner specified.

To confer on the pinion the multiplicity of movement which it requires, it is supplied with *a double hinge or compound joint*, which enables it to move not only in an upward, downward, forward and backward direction, but also at various intermediate degrees of obliquity. An insect furnished with wings thus hinged may, as far as steadiness of body is concerned, be not inaptly compared to a compass set upon gimbals, the universality of the wing-movements rendering any elaborate attempt at balancing quite unnecessary.

In the bird the head of the humerus is convex and somewhat oval (not round), the long axis of the oval being directed from above downwards, *i.e.*, from the dorsal towards the ventral aspect of the bird. The humerus can, therefore, *glide up and down* in the *facettes* occurring on the articular ends of the coracoid and scapular bones with great facility, much in the same way that the head of the radius glides upon the distal end of the humerus. But the humerus has another motion; it moves *like a hinge from before backwards, and vice versa.* The axis of the latter movement is almost at right angles to that of the former. As, however, the shoulder-joint is connected by long ligaments to the body, and can be drawn away from it to the extent of one-eighth of an inch or more, it follows that *a third and twisting movement can be performed*, the twisting admitting of rotation to the extent of something like a quarter of a turn. In raising and extending the wing preparatory to the downward stroke two opposite movements are required, viz., one from before backwards, and another from below upwards. As, however, the axes of these movements are at nearly right angles to each other, a spiral or twisting movement is necessary to run the one into the other—to turn the corner, in fact.

From what has been stated it will be evident that the movements of the wing, particularly at the root, are remarkably free, and very varied. A directing and restraining, as well as a propelling force, is therefore necessary.

Such complex force is to be found in the voluntary muscles which connect the wing with the body in the insect, and which in the bat and bird, in addition to connecting the wing with the body, extend along the pinion even to its tip. It is also to be found in the musculo-elastic and other ligaments. I do not propose entering upon a consideration of the muscular system of the wing of

the bat and bird, as this has been satisfactorily done already. I will, therefore, confine the present remarks to the elastic ligaments, and more especially to those of the bird, as being the most illustrative, alike from their size and situation.

The Wing Flexed and partly Elevated by the Action of Elastic Ligaments—the Nature and Position of such Ligaments in the Pheasant, Snipe, Crested Crane, Swan, &c.—When the wing is drawn away from the body of the bird by the hand the posterior margin of the pinion formed by the primary, secondary, and tertiary feathers rolls down to make a variety of inclined surfaces with the horizon. When, however, the hand is withdrawn, even in the dead bird, the wing instantly folds up; and in doing so, reduces the amount of inclination in the several surfaces referred to. This it does in virtue of certain elastic ligaments, which are put upon the stretch in extension, and which recover their original form and position in flexion. This simple experiment shows that the various inclined surfaces requisite for flight are produced by the mere act of extension and flexion in the dead bird. It is not, however, to be inferred from this circumstance that flight in the animal kingdom is a purely mechanical act any more than ordinary walking is. The muscles, bones, ligaments, feathers, &c. are so adjusted with reference to each other that if the wing is moved at all, it must be moved in the proper direction—an arrangement which enables the bird to fly without thinking just as we can walk without thinking. There cannot, however, be a shadow of a doubt that the bird has the power of controlling its wings both during the down and up strokes; for how otherwise could it steer and direct its course with such precision in obtaining its food? how fix its wings on a level with or above its body for skimming purposes? how form a curve? how fly with, against, or across a breeze? how project itself from a rock directly into space, or how elevate itself from a level surface by the laboured action of its wings?

The wing of the bird is elevated to a certain extent in flight by the reaction of the air upon its under surface; but it is also elevated by muscular action—by the contraction of the elastic ligaments, and by the body falling downwards and forwards in a curve.

That muscular action is necessary is proved by the fact that the pinion is supplied with distinct elevator muscles*—nay, more, that the bird can, and always does, elevate its wing prior to flight, quite independently of the air. When the bird is fairly launched into space the elevator muscles are assisted

* C. J. L. Krarup, a Danish author, gives it as his opinion that the wing is elevated by a vital force, viz., by the contraction of the *pectoralis minor;* this muscle, according to him, acting with $\frac{1}{7}$th the intensity of the *pectoralis major* (the depressor of the wing). He bases his statement upon the fact that in the pigeon the pectoralis minor or elevator of the wing weighs $\frac{1}{8}$th of an ounce, whereas the pectoralis major or depressor of the wing weighs $\frac{7}{8}$ths of an ounce. It ought, however, to be borne in mind that the volume of a muscle does not necessarily determine the precise influence exerted by its action; for the tendon of one muscle may be made to act upon a long lever, and, under favourable conditions, for developing its powers, while that of another muscle may be made to act upon a short lever, and, consequently, under unfavourable conditions.—*On the Flight of Birds*, p. 30. Copenhagen, 1869.

by the falling forward of the body, by the reaction of the air, and by the contraction of the elastic ligaments. The air and the elastic ligaments contribute to the elevation of the wing, but both are obviously under control—they, in fact, form links in a chain of motion which at once begins and terminates in the muscular system.

That the elastic ligaments are subsidiary and to a certain extent under the control of the muscular system in the same sense that the air is, is evident from the fact that voluntary muscular fibres run into the ligaments in question at various points. Thus, in the pheasant, as shown at *a b* of figure 23, Plate XV., red muscular fibres are seen terminating in the fibrous and elastic tissues *c* and *k*. These structures act in conjunction, and fold or flex the forearm on the arm. At *f h* voluntary muscle is seen acting in concert with the elastic ligament *g i* to flex the hand upon the forearm. The arm is drawn towards the body by the elastic ligament *d* and by the muscles *v w*.

The elastic ligaments, while occupying a similar position in the wings of all birds, are variously constructed in the several species. In the common snipe, for example, as represented at figure 21, Plate XV., the voluntary muscular slip *a* terminates in the fibro-elastic band *k;* this again being geared to voluntary muscle *x*, and to certain musculo-fibrous bands *j*. Their conjoined action is to flex the forearm upon the arm, the arm being drawn towards the body by a musculo-fibrous ligament *d, e*. The elastic ligament *g i* flexes the hand upon the forearm, and the ligament *r* the fingers upon the hand. A somewhat similar arrangement is formed in the wing of the crested crane, as shown at figure 24, Plate XVI. Thus, at *a, b*, voluntary muscular slips are seen terminating in the elastic band *k*, this splitting up into two portions at *k, m*. A somewhat similar band is seen at *j*, and all three are united to, and act in conjunction with, the great fibro-elastic web *c* to flex the elbow. The musculo-fibro-elastic ligament *f g, h i*, as already explained, envelopes the root of each primary, secondary, and tertiary feather. It also forms a symmetrical network, so that it at once supports the feathers and limits their peculiar actions. In the swan the muscular slip which corresponds to *a* of figure 24, Plate XVI. (crested crane), terminates in a fibrous band, which corresponds to *k;* but the muscular slip corresponding to *b* terminates in a well-defined tendon, not in the fibrous band *m*, but in a distinct muscle, 5 inches in length and $\frac{1}{4}$ of an inch in breadth. This muscle is situated in the anterior margin of the wing, midway between the shoulder and wrist joints, and exercises a most potent influence in folding the elbow. The band marked *j* in the crane's wing is at least four times broader in the swan's wing.

The Elastic Ligaments more Highly Differentiated in Wings which Vibrate Rapidly.—From what has been stated, it will be evident that the elastic ligaments of the swan are more complicated and more liberally supplied with

voluntary muscle than those of the crane, and this is no doubt owing to the fact that the wings of the swan are driven at a much higher speed than those of the crane. In the snipe the wings are vibrated very much more rapidly than in the swan, and as a consequence we find that the fibro-elastic bands are not only greatly increased, but they are also geared to a much greater number of voluntary muscles, all which seems to prove that the elastic apparatus employed by nature for recovering or flexing the wing towards the end of the down stroke become more and more highly differentiated in proportion to the rapidity with which the wing is moved.* The reason for this is obvious. If the wing is to be worked at a higher speed, it must, as a consequence, be more rapidly flexed and extended. The rapidity with which the wing of the bird is extended and flexed is in some instances exceedingly great; so great, in fact, that it escapes the eye of the ordinary observer. The rapidity with which the wing darts in and out in flexion and extension would be quite inexplicable, but for a knowledge of the circumstance that the different portions of the pinion are disposed at various angles of inclination (*vide x, s, t, w* of figures 9 and 10, Plate XII.), these angles being instantly increased or diminished by the slightest quiver of the muscular and fibro-elastic systems. If we take into account the fact that the wing of the bird is recovered or flexed by the combined action of voluntary muscles and elastic ligaments; that it is elevated to a considerable extent by voluntary muscular effort; and that it is extended and depressed entirely by muscular exertion, we shall have difficulty in avoiding the conclusion that the wing is thoroughly under the control of the muscular system, not only in flexion and extension, but also throughout the entire down and up strokes.

An arrangement in every respect analogous to that just described is found in the wing of the bat, the covering or web of the wing in this instance forming the principal elastic ligament. In fact, the bones and muscles of the bat's wing, and the inclined surfaces made by its different portions with each other and with the horizon during flexion and extension, and during the down and up strokes, so closely resemble those of the bird that a separate description is unnecessary. From the foregoing description it will be obvious that the wing of the bird and bat is a highly differentiated organ, endowed with independent movements, which enable it to direct and control the air for a purpose.

How Balancing is Effected in Flight.—The manner in which insects, bats, and birds balance themselves in the air has hitherto, and with reason, been regarded a mystery, for it is difficult to understand how they maintain their equilibrium when the wings are beneath their bodies. Figures 3 and 4, page 338, throw considerable light on the subject in the case of the insect. In those figures the space (*a, g*) mapped out by the wing during its vibrations is entirely

* A careful account of the musculo-elastic structures occurring in the wing of the pigeon is given by Mr Macgillivray in his admirable "History of British Birds," pages 37 and 38. Lond. 1837.

occupied by it; *i.e.*, the wing (such is its speed) is in every portion of the space at nearly the same instant, the space representing what is practically a solid basis of support. As, moreover, the wing is jointed to the upper part of the body (thorax) by a universal joint, which admits of every variety of motion, the insect is always suspended (very much as a compass set upon gimbals is suspended), the wings, when on a level with the body, vibrating in such a manner as to occupy a circular area, in the centre of which the body is placed (*vide r d b f* of fig. 51, page 399). The wings, when vibrating above and beneath the body occupy a conical area, the apex of the cone being directed upwards when the wings are below the body, and downwards when beneath it. Those points are well seen in the bird at figures 18 and 19, Plate XIV. In figure 18 the inverted cone formed by the wings when above the body is represented, and in figure 19 that formed by the wings when below the body is given. In these figures it will be observed that the body, from the insertion of the roots of the wings into its upper portion, is always suspended, and this, of course, is equivalent to suspending the centre of gravity. In the bird and bat, where the stroke is delivered more vertically than in the insect, the *basis of support* is increased by the tip of the wing folding inwards and backwards in a more or less horizontal direction at the end of the down stroke; and outwards and forwards at the end of the up stroke. This is accompanied by the rotation of the outer portion of the wing upon the wrist as a centre (*vide t* of figures 9 and 10, Plate XII.), the tip of the wing, because of the ever varying position of the wrist, describing an ellipse. In insects whose wings are broad and large (butterfly), and which are driven at a comparatively low speed, the balancing power is diminished. In insects whose wings, on the contrary, are long and narrow (blow-fly), and which are driven at a high speed, the balancing power is increased. It is the same with short and long winged birds, so that the function of balancing is in some measure due to the form of the wing, and the speed with which it is driven, the long wing and the wing vibrated with great energy increasing the capacity for balancing. When the body is light and the wings very ample (butterfly and heron), the descent of the wing and the reaction of the air during the up stroke displaces the body to a marked extent. When, on the other hand, the wings are small and the body large, the reaction produced on the trunk by the vibration of the wing is scarcely perceptible. Apart, however, from the shape and dimensions of the wing, and the rapidity with which it is urged, it must never be overlooked that all wings (as has been pointed out) are attached to the bodies of the animals bearing them by some form of universal joint, and in such a manner that the bodies, whatever the position of the wings, are accurately balanced, and swim about precisely after the fashion of a compass set upon gimbals. To such an extent is this true, that the position of the wing is a matter of indifference. Thus the pinion may be

above, beneath, or on a level with the body; or it may be directed forwards, backwards, or at right angles to the body. In either case the body is balanced mechanically and without effort. To prove this point, I made an artificial wing and body, and united the one to the other by a universal joint. I found, as I had anticipated, that place the wing in whatever position I chose, whether above, beneath, or on a level with the body, or at either side of it, the body almost instantly attained a position of rest. The body was, in fact, equally suspended and balanced from all points.

Rapidity of Wing Movements partly Accounted for.—Much surprise has been expressed at the enormous rapidity with which some wings are made

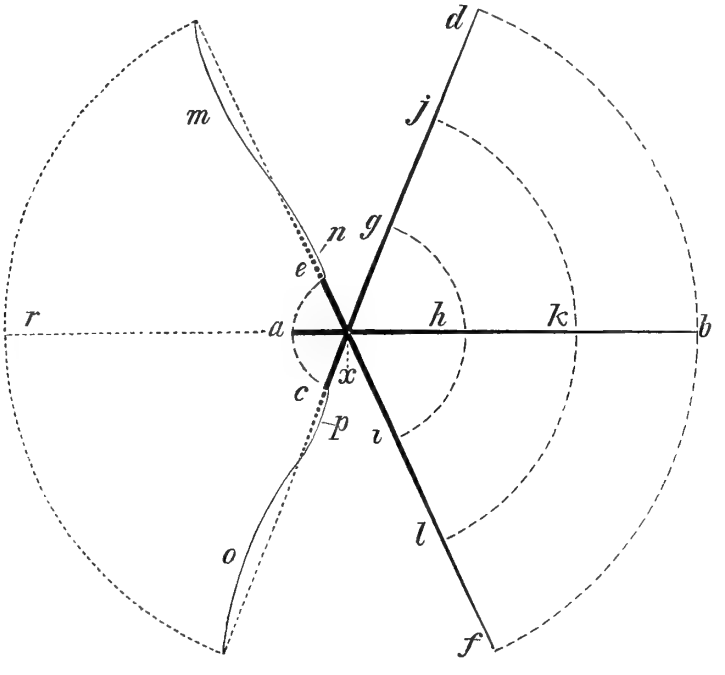


Fig. 51.*

to vibrate. The wing of the insect is, as a rule, very long and narrow. As a consequence, a comparatively slow and very limited movement at the root confers great range and immense speed at the tip, the speed of each portion of the wing increasing as the root of the wing is receded from. This is explained on a principle well understood in mechanics, viz., that when a rod hinged at one end is made to move in a circle, the tip or free end of the rod describes a much wider circle *in a given time* than a portion of the rod nearer the

* In this diagram I have represented the wing by a straight *rigid* rod. The natural wing, however, is curved, *flexible*, and *elastic*. It likewise *moves in curves*, the curves being most marked towards the end of the down and up strokes, as shown at *m*, *n*, *o*, *p*. The curves, which are double figure of 8 curves, are obliterated towards the middle of the strokes (*r*, *a*). This remark holds true of all natural wings, and of all artificial wings properly constructed. The curves and the reversal thereof are necessary to give continuity of motion to the wing during its vibrations, and what is not less important, to enable the wing alternately to seize and dismiss the air.

hinge. Thus if *a b* of figure 51 (p. 399) be made to represent the rod hinged at *x*, it travels through the space *d b f* in the same time that it travels through *j k l;* and through the space *j k l* in the same time that it travels through the space *g h i;* and through the space *g h i* in the same time it travels through *e a c*, which is the area occupied by the thorax of the insect. If, however, the rod *a b* travels through the space *d b f* in the same time that it travels through the space *e a c*, it follows of necessity that the portion of the rod marked *a* moves very much slower than that marked *b*. The muscles of the insect are applied at the point *a*, as short levers (the point referred to corresponding to the thorax of the insect), so that a comparatively slow and limited movement at the root of the wing produces the marvellous speed observed at the tip, the tip and body of the wing being those portions which occasion the blur or impression produced on the eye by the rapidly oscillating pinion. But for this mode of augmenting the speed originally inaugurated by the muscular system, it is difficult to comprehend how the wings could be driven at the velocity attributed to them. The wing of the blow-fly is said to make 300 strokes per second, *i.e.*, 18,000 strokes per minute. Now it appears to me that muscles to contract at the rate of 18,000 times in the minute would be exhausted in a very few seconds, a state of matters which would render the continuous flight of insects impossible. (The heart contracts only between 60 and 70 times in a minute.) I am therefore disposed to believe that the number of contractions made by the thoracic muscles of insects has been greatly overstated, the high speed at which the wing is made to vibrate being due less to the separate and sudden contractions of the muscles at its roots than to the fact that the speed of the different parts of the wing is increased in a direct ratio as the portions in question are removed from the driving point, as already explained. Speed is certainly a matter of great importance in wing movements, as the elevating and propelling power of the pinion depends to a great extent upon this condition. Speed, however, may be produced in two ways —either by a series of separate and opposite movements, such as is witnessed in the action of a piston, or by a series of separate and opposite movements, acting upon an instrument so designed that a movement applied at one part increases in rapidity as the point of contact is receded from, as happens in the wing. In the piston movement the motion is uniform, or nearly so, all parts of the piston travelling at very much the same speed. In the wing movements, on the contrary, the motion is gradually accelerated towards the tip of the pinion, where the pinion is most effective as an elevator, and decreased towards the root, where it is least effective ; an arrangement calculated to reduce the number of muscular contractions, while it contributes to the actual power of the wing. This hypothesis, it will be observed, guarantees to the wing a very high speed, with comparatively few reversals and comparatively few muscular contractions.

In the bat and bird the wings do not vibrate with the same rapidity as in

the insect, and this is accounted for by the circumstance, that in them the muscles do not act exclusively at the root of the wing. In the bird and bat the muscles run along the wing towards the tip for the purpose of flexing or folding the wing prior to the up stroke, and for opening out or expanding it prior to the down stroke.

As the wing must be folded or flexed and opened out or expanded every time the wing rises and falls, and as the muscles producing flexion and extension are long muscles with long tendons, which act at long distances as long levers, and comparatively slowly, it follows that the great short muscles (pectorals, &c.) situated at the root of the wing must act slowly likewise, as the muscles of the thorax and wing of necessity act together to produce one pulsation or vibration of the wing. What the wing of the bat and bird loses in speed it gains in power, the muscles of the bird and bat's wing acting directly upon the points to be moved, and under the most favourable conditions. In the insect, on the contrary, the muscles act indirectly, and consequently at a disadvantage. If the pectorals only acted, they would act as short levers, and confer on the wing of the bat and bird the rapidity peculiar to the wing of the insect. The tones produced by the bird's wing would in this case be heightened. The swan in flying produces a loud whistling sound, and the pheasant, partridge, and grouse a sharp whirring noise like the stone of a knife-grinder.

It is a mistake to suppose, as many do, that the tone or note produced by the wing during its vibrations is a true indication of the number of beats made by it in any given time. This will be at once understood, when I state that a long wing will produce a higher note than a shorter one driven at the same speed and having the same superficial area, from the fact that the tip and body of the long wing will move through a greater space in a given time than the tip and body of the shorter wing. This is occasioned by all wings being jointed at their roots, the sweep made by the different parts of the wing in a given time being longer or shorter in proportion to the length of the pinion. It ought, moreover, not to be overlooked that in insects the notes produced are not always referrible to the action of the wings, these, in many cases, being traceable to movements induced in the legs and other parts of the body.

It is a curious circumstance that if portions be removed from the posterior margins of the wings of a buzzing insect, such as the wasp, bee, blue-bottle fly, &c., the note produced by the vibration of the pinions is raised in pitch. This is explained by the fact that an insect, whose wings are curtailed, requires to drive them at a much higher speed in order to sustain itself in the air. That the velocity at which the wing is urged is instrumental in causing the sound, is proved by the fact that in slow flying insects and birds no note is produced; whereas in those which urge the wing at a high speed, a note is elicited which corresponds within certain limits to the number of vibrations and the form of

the wing. It is the posterior or thin flexible margin of the wing which is more especially engaged in producing the sound, and if this be removed, or if this portion of the wing, as is the case in the bat and owl, be constructed of very soft materials, the character of the note is altered. An artificial wing, if properly constructed and impelled at a sufficiently high speed, emits a drumming noise, which closely resembles the note produced by the vibration of short-winged, heavy-bodied birds, all which goes to prove that sound is a concomitant of rapidly vibrating wings.

ARTIFICIAL FLIGHT.

The subject of artificial flight, notwithstanding the large share of attention bestowed upon it, has been particularly barren of results. This is the more to be regretted, as the interest which has been taken in it from early Greek and Roman times has been universal. The unsatisfactory state of the question is to be traced to a variety of causes, the most prominent of which are—

1*st*, The extreme difficulty of the problem.

2*d*, The incapacity or theoretical tendencies of those who have devoted themselves to its elucidation.

3*d*, The great rapidity with which wings, especially insect wings, vibrate, and the difficulty experienced in analysing their movements.

4*th*, The great weight of all flying things when compared with a corresponding volume of air.

5*th*, The discovery of the balloon, which has retarded the science of aërostation, by misleading men's minds and causing them to look for a solution of the problem by the aid of a machine lighter than the air, and which has no analogue in nature. Flight has been unusually unfortunate in its votaries. It has been cultivated by profound thinkers, especially mathematicians, who have worked out innumerable theorems, but who, it would appear, never bethought them of verifying their results by experiment; and by uneducated charlatans who, despising the abstractions of science, have made the most ridiculous attempts at a practical solution of the problem. Thus bandied about, artificial flight has become the idol of a few and the jest of the many. The term has been employed, on the one hand, to represent the highest soarings of the human mind, and on the other, to typify the extinction or aberration of intellect, the word flighty signifying whatever is utopian or foolish.

Flight, as the question stands at present, may be divided into two principal varieties which represent two great sects or schools—

1*st*, The Balloonists, or those who advocate the employment of a machine specifically lighter than the air.

2*d*, Those who believe that weight is necessary to flight.

The second school may be subdivided into (*a*) those who advocate the

employment of rigid inclined planes driven forward in a straight line, or revolving planes (aërial screws); and (*b*) such as trust for elevation and propulsion to the vertical flapping of wings.

Balloon.—The balloon, as all are aware, is constructed on the obvious principle that a machine lighter than the air must necessarily rise through it. The MONTGOLFIER brothers invented such a machine in 1782. Their balloon consisted of a paper globe or cylinder, the motor power being super-heated air supplied by the burning of vine twigs under it. The Montgolfier or fire balloons, as they were called, were superseded by the hydrogen gas balloon of MM. CHARLES and ROBERT, this being in turn supplanted by the ordinary gas balloon of Mr GREEN. Since the introduction of coal gas in the place of hydrogen gas, no radical improvement has been effected, all attempts at guiding balloons having signally failed. This arises from the vast extent of surface which they necessarily present, rendering them a fair conquest to every breeze that blows, and because the power which animates them is a mere lifting power which, in the absence of wind, must act in a vertical line, all other motion being extraneous and foreign to it. It consequently rises through the air in opposition to the law of gravity, very much as a dead bird falls in a downward direction in accordance with it. Having no hold upon the air, this cannot be employed as a fulcrum for regulating its movements, and hence the cardinal difficulty of ballooning as an art.

Finding that no marked improvement has been made in the balloon since its introduction in 1782, the more advanced thinkers have within the last quarter of a century turned their attention in an opposite direction, and have come to regard flying creatures, all of which are much heavier than the air, as the true models for flying machines. An old doctrine is more readily assailed than uprooted, and accordingly we find the followers of the new faith met by the assertion that insects and birds have large air cavities in their interior, that those cavities contain heated air, and this heated air in some mysterious manner contributes to, if it does not actually produce, flight. No argument could be more fallacious. To render a flying creature buoyant by means of air-cells, it would require to have its superficial area increased a thousand fold (would, in fact, require to be converted into a balloon); and, besides, many admirable fliers, such as the bats, have no air-cells, while many birds, the apteryx for example, and many animals never intended to fly, such as the orang-outang and a large number of fishes, are provided with them. It may therefore be reasonably concluded that flight is in no way connected with air-cells, and the best proof that can be adduced is to be found in the fact that it can be performed to perfection in their absence.

The Inclined Plane.—The modern school of flying is in some respects quite as irrational as the ballooning school.

The favourite idea with most is the wedging forward of *an inclined plane* upon the air by means of a "*vis a tergo.*"

The inclined plane may be made to advance in *a horizontal line* or made *to rotate* in the form of a screw. Both plans have their adherents. The one recommends a large supporting area extending on either side of the weight to be elevated, the surface of the supporting area making an all but inappreciable angle with the horizon, the whole being wedged forward by the action of vertical screw propellers. This was the plan suggested by HENSON and STRINGFELLOW, and partly carried out by the latter.

WENHAM* has advocated the employment of *superimposed planes,* with a view to augmenting the support furnished while it diminishes the horizontal space occupied by the planes. These planes WENHAM designates *Acroplanes.* They are inclined at a very slight angle to the horizon, and are wedged forward either by the weight to be elevated or by the employment of vertical screws. WENHAM'S plan was adopted by STRINGFELLOW† in a model which he exhibited at the Aëronautical Society's Exhibition, held at the Crystal Palace in the summer of 1868.

The subjoined woodcut (fig. 52), taken from a photograph, gives a very good

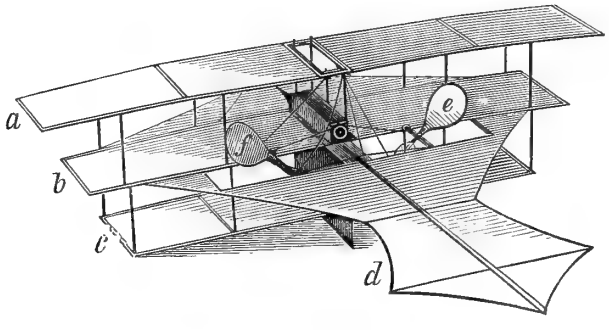


Fig. 52.

idea of the model in question, *a b c* representing the superimposed planes, *d* the tail, and *e f* the vertical screw propellers.

The superimposed planes (*a b c*) in this machine contained a sustaining area of 28 square feet in addition to the tail (*d*).

Its engine represented a third of a horse power, and the weight of the whole (engine, boiler, water, fuel, superimposed planes, and propellers) was under 12 lbs. Its sustaining area, if that of the tail (*d*) be included, was something like 36 square feet, *i.e.*, 3 square feet for every pound—the sustaining area of the gannet (p. 385), it will be remembered, being less than one foot of wing for every two pounds of body.

* On Aërial Locomotion, by F. H. WENHAM, Esq., World of Science for June, 1867.
† Flying Machines, by F. W. BREARY, Esq., Popular Science Review for January, 1869.

The model was forced by its propellers along a wire at a great speed, but, so far as I could determine, failed to lift itself notwithstanding its extreme lightness and the comparatively very great power employed.*

Mr HENSON'S† aërial machine was very similar in principle to Mr STRINGFELLOW'S. "The chief feature of the invention was the very great expanse of its sustaining planes, which were larger in proportion to the weight it had to carry than those of many birds. The machine advanced with its front edge a little raised, the effect of which was to present its under surface to the air over which it passed, the resistance of which, acting upon it like a strong wind on the sails of a windmill, prevented the descent of the machine and its burden. The sustaining of the whole, therefore, depended upon the speed at which it travelled through the air, and the angle at which its under surface impinged on the air in its front. . . . The machine, fully prepared for flight, was started from the top of an inclined plane, in descending which it attained a velocity necessary to sustain it in its further progress. That velocity would be gradually destroyed by the resistance of the air to the forward flight; it was, therefore, the office of the steam engine and the vanes it actuated simply to repair the loss of velocity; it was made therefore only of the power and weight necessary for that small effect. . . ." The editor of "Newton's Journal of Arts and Science" speaks of it thus—"The apparatus consists of a car containing the goods, passengers, engines, fuel, &c., to which a rectangular frame, made of wood or bamboo cane, and covered with canvas or oiled silk, is attached. This frame extends on either side of the car in a similar manner to the outstretched wings of a bird; but with this difference, that the frame is immovable. Behind the wings are two vertical fan wheels, furnished with oblique vanes, which are intended to propel the apparatus through the air. The rainbow-like circular wheels are the propellers, answering to the wheels of a steam-boat, and acting upon the air after the manner of a windmill. These wheels receive motion from bands and pulleys from a steam or other engine contained in the car. To an axis at the stern of the car a triangular frame is attached, resembling the tail of a bird, which is also covered with canvas or oiled silk. This may be expanded or contracted at pleasure, and is moved up and down for the purpose of causing the machine to ascend or descend. Beneath the tail is a rudder for directing the course of the machine to the right or to the left; and to facilitate the steering a sail is stretched between two masts which rise from the car. The amount of canvass or oiled silk necessary for buoying up the machine is stated to be equal to one square foot for each half pound of weight.‡

* Mr STRINGFELLOW stated that his machine occasionally left the wire, and was sustained by its superimposed planes alone.

† Mr HENSON designed his aërostat in 1843.

‡ Astra Castra, by HATTON TURNER, Esq. London, 1865, pages 311 and 312.

The idea embodied by HENSON, STRINGFELLOW, and WENHAM is plainly that of a boy's kite sailing upon the wind. The kite, however, is a more perfect flying apparatus than that furnished by HENSON, STRINGFELLOW, and WENHAM, inasmuch as the inclined plane formed by its body strikes the air at various angles—the angles varying according to the length of string, strength of breeze, length and weight of tail, &c. HENSON'S, STRINGFELLOW'S, and WENHAM'S methods, although carefully tried, have hitherto failed. The objections are numerous. In the first place, the supporting planes (aëroplanes or otherwise) are *rigid.* This is a point to which I wish particularly to direct attention. Second, They stroke the air *at a given angle.* Here again, there is a departure from nature. Third, A machine so constructed must be precipitated from a height or driven along the surface of the land or water at a high speed to supply it with initial velocity. Fourth, It is unfitted for flying with the wind unless its speed greatly exceeds that of the wind. Fifth, It would have considerable difficulty in flying across the wind, and considerable risk would be incurred in landing because of the velocity attained. Sixth, The sustaining surfaces are comparatively very large. They are, moreover, passive or dead surfaces, *i.e.*, they have no power of moving or accommodating themselves to altered circumstances. In this respect they somewhat resemble the surfaces presented by a balloon—their great extent rendering them liable to be seized and tossed by the wind.

The Aërial Screw.—Our countryman, Sir GEORGE CAYLEY, gave the first practical illustration of the efficacy of the screw as applied to the air in 1796. In that year he constructed a small machine consisting of two screws made of quill feathers. The screws were each composed of four feathers stuck in a piece of cork, the corks being drilled in the centre to receive a driving shaft or axis. To the shaft a whalebone spring, with a string which coiled round the shaft (and by which the spring was wound up), was affixed. By turning the upper screw (the lower one being secured) a sufficient number of times, the proper degree of tension was conferred on the spring; and the instant the apparatus was liberated it flew into the air. CAYLEY'S screws were peculiar, inasmuch as they were superimposed and rotated in opposite directions. He estimated that if the area of the screws was increased to 200 square feet, and moved by a man, they would elevate him. CAYLEY'S interesting experiment is described at length, and the apparatus figured in "Nicholson's Journal" for 1809, p. 175. In 1842 Mr PHILLIPS also succeeded in elevating a model by means of revolving fans. Mr PHILLIPS'S model was made entirely of metal, and when complete and charged weighed 2 lbs. It consisted of a boiler or steam generator and four fans supported between eight arms. The fans were inclined to the horizon at an angle of 20°, and through the arms the steam rushed on the principle discovered by HERO of Alexandria. By the escape of steam from the arms, the fans were

made to revolve with immense energy, so much so that the model rose to a great altitude, and flew across two fields before it alighted. The motive power employed in the present instance was obtained from the combustion of charcoal, nitre, and gypsum, as used in the original fire annihilator, the products of combustion mixing with water in the boiler, and forming gas charged steam, which was delivered at a high pressure from the extremities of the eight arms. This model is remarkable as being probably the first which actuated by steam has flown to any considerable distance.* The French have espoused the aërial screw with great enthusiasm, and within the last few years (1863) M. M. NADAR,† DE PONTIN D'AMÉCOURT, and DE LA LANDELLE have constructed clockwork models (*orthopteres*), which not only raise themselves into the air, but carry a

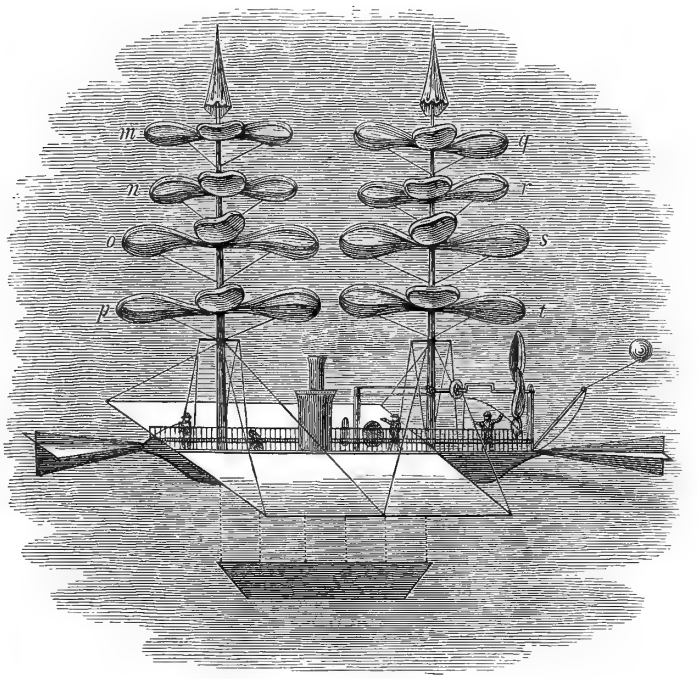


Fig. 53. Flying Machine designed by M. DE LA LANDELLE.

certain amount of freight. These models are exceedingly fragile, and because of the prodigious force required to propel them usually break after a few trials. The above woodcut (figure 53) embodies M. DE LA LANDELLE's ideas.

* Report on the First Exhibition of the Aëronautical Society of Great Britain, held at the Crystal Palace, London, in June 1868, page 10.

† Mons. NADAR, in a paper written in 1863, enters very fully into the subject of artificial flight, as performed by the aid of the screw. Liberal extracts are given from NADAR's paper in "Astra Castra," by Captain HATTON TURNER. London, 1865, page 340. To TURNER's handsome volume the reader is referred for much curious and interesting information on the subject of Aërostation.

In the helecopteric models made by M. M. NADAR, PONTIN D'AMÉCOURT, and DE LA LANDELLE, the screws (*m n o p q r s t*, figure 53, p. 407) are arranged in tiers, *i.e.*, the one screw is placed above the other. In this respect they resemble the aëro-planes recommended by Mr WENHAM, and tested by Mr STRINGFELLOW, (compare *m n o p q r s t* of fig. 53. p. 407, with *a b c* of fig. 52, p. 404). The superimposed screws, as already explained, were first figured and described by Sir GEORGE CAYLEY. The French screws, and that employed by Mr PHILLIPS, are *rigid or unyielding*, and strike the air *at a given angle*, and herein, I believe, consist their principal defect. This arrangement results in a ruinous expenditure of power, and is accompanied by a great amount of slip. The aërial screw, and the machine to be elevated by it, can be set in motion without a preliminary run, and in this respect it has the advantage over the machine supported by sustaining planes. It has, in fact, a certain amount of inherent motion, its sustaining surfaces being active or moving surfaces. It is accordingly more independent than the machine designed by HENSON, STRINGFELLOW, and WENHAM.

I may observe with regard to the system of rigid inclined planes wedged forward at a given angle in a line or in a circle, that it does not embody the principle carried out in nature.

The wing of a flying creature, as I have taken pains to show, is *not rigid;* neither does it always attack the air *at one angle.* On the contrary, it is capable of moving in all its parts, and attacks the air at *an infinite variety of angles.* Above all, the surface exposed by a natural wing, when compared with the great weight it is capable of elevating, is remarkably small. This is accounted for by the length and the great range of motion of natural wings, the latter enabling the wings to convert large tracts of air into supporting areas. It is also accounted for by the multiplicity of the movements of natural wings, these enabling the pinions to create and rise upon currents of their own forming, and to select and utilise existing currents.

If any one watches an insect, a bat, or a bird when dressing its wings, he will observe that it can incline the under surface of the wing at a great variety of angles to the horizon. This it does by causing the wing to rotate along its anterior or thick margin, or by twisting the posterior or thin yielding margin around the anterior or thick margin. As a result of this movement, the two margins are forced into double and opposite curves, and the wing converted into *a plastic helix or screw.* He will further observe that the bat and bird, and some insects, have, in addition, the power of folding and drawing the wing towards the body during the up stroke, and of pushing it away from the body and extending it during the down stroke, so as alternately to diminish and increase its area, arrangements necessary to decrease the amount of resistance experienced by the wing during its ascent, and increase it during its descent. It

is scarcely necessary to add, that in the aëro-planes and aërial screws, as at present constructed, no provision whatever is made for suddenly increasing or diminishing the sustaining area, of conferring elasticity upon it, or of giving to the supporting surfaces that infinite variety of angles which would enable them to seize and disentangle themselves from the air with rapidity. Many investigators are of opinion that flight is a question of mere levity and power, and that if a machine could only be made light enough and powerful enough, it must of necessity fly, whatever the nature of its flying surfaces. A grave fallacy lurks here. Birds are not more powerful than quadrupeds of equal size, and STRINGFELLOW's machine, which, as we have seen, only weighed 12 *lbs.*, exerted *one-third of a horse power*. The probabilities therefore, are, that flight is dependent to a great extent on the nature of the flying surfaces, and the mode of applying those surfaces to the air.

Artificial Wings (BORELLI's *Views*).—With regard to the production of *flight by the flapping of wings*, much may and has been said. Of all the methods yet proposed, it is unquestionably by far the most ancient. Discrediting as apocryphal the famous story of DÆDALUS and his waxen wings, we certainly have a very graphic account of artificial wings in the "De Motu Animalium" of BORELLI, published as far back as 1680, *i.e.*, nearly two centuries ago.*

Indeed it will not be too much to affirm, that to this distinguished physiologist and mathematician belongs almost all the knowledge we at present possess of artificial wings and their actions. He was well acquainted with the properties of the wedge, as applied to flight, and he was likewise cognisant of the flexible and elastic properties of the wing. To him is to be traced the purely mechanical theory of the wing's action. He figured a bird with artificial wings, each wing consisting of *a rigid rod in front* and *flexible feathers* behind. I have thought fit to reproduce BORELLI's figure, both because of its great antiquity, and because it is eminently illustrative of his text.†

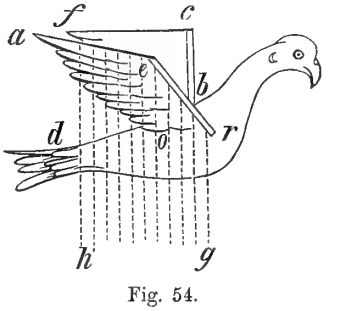


Fig. 54.

The wings, as a reference to fig. 54 will show, are represented as striking vertically downwards (*g h*). They remarkably accord with those described by STRAUS-DURCKHEIM, GIRARD, and quite recently by Professor MAREY.‡

BORELLI was of opinion that flight resulted from the application of an inclined plane, which beats the air, and which has a wedge action. He, in fact, endeavours to prove that a bird wedges itself forward upon the air by the perpendicular

* BORELLI. De Motu Animalium. Sm. 4to. 2 vols. Romæ 1680.

† "De Motu Animalium," Lugduni Batavorum apud Petrum Vander. Anno MDCLXXXV. Tab. XIII. figure 2. (New edition.)

‡ Revue des Cours Scientifiques de la France et de l'Etranger. Mars 1869.

vibration of its wings, the wings during their action forming a wedge, the base of which (*c b e*) is directed towards the head of the bird, the apex (*a f*) being directed towards the tail (*d*). This idea is worked out in propositions 195 and 196 of the first part of BORELLI's book. In proposition 195 he explains how, if a wedge be driven into a body, the wedge will tend to separate that body into two portions; but that if the two portions of the body be permitted to react upon the wedge, they will communicate *oblique impulses* to the sides of the wedge, and expel it, base first, in a straight line.

Following up the analogy, BORELLI endeavours to show in his 196th proposition, "that if the air acts obliquely upon the wings, or the wings obliquely upon the air (which is, of course, a wedge action), the result will be *a horizontal transference of the body of the bird.*" In the proposition referred to (196) BORELLI states—"If the expanded wings of a bird suspended in the air shall strike the undisturbed air beneath it with a motion *perpendicular to the horizon*, the bird will fly *with a transverse motion* in a plane parallel with the horizon." In other words, if the wings *strike vertically downwards*, the bird will fly *horizontally forwards.* He bases his argument upon the belief that the anterior margins of the wings are *rigid and unyielding*, whereas the posterior and after parts of the wings are *more or less flexible*, and readily give way under pressure. If, he adds, the wings of the bird be expanded, and the under surfaces of the wings be struck by the air *ascending perpendicularly to the horizon*, with such a force as shall prevent the bird gliding downwards (*i.e.*, with a tendency to glide downwards) from falling, it will be urged *in a horizontal direction.* This follows because, in BORELLI's opinion, the two osseous rods (*virgæ*) forming the anterior margins of the wings resist the upward pressure of the air, and so retain their original form (literally extent or expansion), whereas the flexible after parts of the wings (posterior margins) are pushed up and approximated to form a cone, the apex of which (*vide a f* of figure 54, p. 409) is directed towards the tail of the bird. In virtue of the air playing upon and compressing the sides of the wedge formed by the wings, the wedge is driven forwards in the direction of its base (*c, b, e*), which is equivalent to saying that the wings carry the body of the bird to which they are attached *in a horizontal direction.*" BORELLI restates the same argument in different words, as follows:—

"If," he says, "the air under the wings be struck by the flexible portions of the wings (*flabella*, literally fly flaps or small fans) with a motion perpendicular to the horizon, the sails (*vela*) and flexible portions of the wings (*flabella*) will yield in an upward direction, and form a wedge, the point of which is directed towards the tail. Whether, therefore, the air strikes the wings from below, or the wings strike the air from above, the result is the same—the posterior or flexible margins of the wings *yield in an upward direction*, and in so doing urge the bird in a *horizontal direction.*"

In his 197th proposition, BORELLI follows up and amplifies the arguments contained in propositions 195 and 196. Thus, he observes, "It is evident that the object of flight is to impel birds upwards, and keep them suspended in the air, and also to enable them to wheel round in a plane parallel to the horizon. The first (or upward flight) could not be accomplished unless the bird were impelled upwards by frequent leaps or vibrations of the wings, and its descent prevented. And because the downward tendency of heavy bodies is perpendicular to the horizon, the vibration of the plain surfaces of the wings must be made by striking the air beneath them in a direction perpendicular to the horizon, and in this manner nature produces the suspension of birds in the air.

With regard to the second or transverse motion of birds (*i.e.*, horizontal flight) some authors have strangely blundered; for they hold that it is like that of boats, which, being impelled by oars, moved horizontally in the direction of the stern, and pressing on the resisting water behind, leaps with a contrary motion, and so are carried forward. In the same manner, say they, the wings vibrate towards the tail with a horizontal motion, and likewise strike against the undisturbed air, by the resistance of which they are moved forward by a reflex motion. But this is contrary to the evidence of our sight as well as to reason; for we see that the larger kinds of birds, such as swans, geese, &c., never vibrate their wings, when flying, towards the tail with a horizontal motion like that of oars, but always bend them downwards, and so describe circles raised perpendicularly to the horizon.*

Besides, in boats the horizontal motion of the oars is easily made, and a perpendicular stroke on the water would be perfectly useless, inasmuch as their descent would be impeded by the density of the water. But in birds such a horizontal motion (which indeed would rather hinder flight) would be absurd, since it would cause the ponderous bird to fall headlong to the earth; whereas it can only be suspended in the air by constant vibration of the wings perpendicular to the horizon. Nature was thus forced to show her marvellous skill in producing a motion which, by one and the same action, should suspend the bird in the air, and carry it forward in a horizontal direction. This is effected by striking the air below perpendicularly to the horizon, but with oblique strokes—an action which is rendered possible only by the flexibility of the feathers, for the fans of the wings in the act of striking acquire the form of a wedge, by the forcing out of which, the bird is necessarily moved forwards in a horizontal direction."

The points which BORELLI endeavours to establish are these:—

First, That the action of the wing is a wedge action.

* It is clear from the above that BORELLI did not know that the wings of birds strike *forwards* as well as downwards during the down stroke. He seems to have been equally ignorant of the fact that the wings of insects vibrate in a more or less horizontal direction.

Second, That the wing consists of two portions—*a rigid* anterior portion, and a *non-rigid* flexible portion. The rigid portion he represents in his artificial bird (figure 54, page 409) as consisting of *a rod* (*e, r*), the yielding portion of *feathers* (*a, o*).

Third, That if the air strikes the under surface of the wing perpendicularly in a direction from below upwards, the flexible portion of the wing will yield in an upward direction, and form a wedge with its neighbour.

Fourth, Similarly and conversely, if the wing strikes the air perpendicularly from above, the posterior and flexible portion of the wing will yield and be forced in an upward dirction.

Fifth, That this *upward yielding* of the posterior or flexible margin of the wing results in and necessitates *a horizontal transference* of the body of the bird.

Sixth, That to sustain a bird in the air the wings must strike *vertically downwards,* as this is the direction in which a heavy body, if left to itself, would fall.

Seventh, That to propel the bird in a horizontal direction, the wings must descend in a perpendicular direction, and the posterior or flexible portions of the wings *yield in an upward direction,* and in such a manner as virtually to communicate *an oblique action* to them.

Eighth, That the feathers of the wing are *bent in an upward direction* when the wing *descends,* the upward bending of the elastic feathers contributing to the horizontal travel of the body of the bird.

I have been careful to expound Borelli's views for several reasons :—

1*st,* Because the purely mechanical theory of the wing's action is to be traced to him.

2*d,* Because his doctrines have remained unquestioned for nearly two centuries, and have been adopted by all the writers since his time, without, I regret to say in the great majority of cases, any acknowledgment whatever.

3*d,* Because his views have been revived by the modern French school, and

4*th,* Because in commenting upon and differing from Borelli I will necessarily comment upon and differ from all his successors.

The Duke of Argyll agrees with Borelli in believing that the wing invariably strikes *perpendicularly downwards.* His words are—"Except for the purpose of arresting their flight birds can never strike except *directly downwards;* that is, against the opposing force of gravity." Professor Owen in his "Comparative Anatomy," Mr M'Gillivray in his "British Birds," Mr Bishop in his article Motion in the "Cyclopedia of Anatomy and Physiology," and M. Liais "on the flight of birds and insects" in the "Annals of Natural History," all assert that the stroke is delivered *downwards* and more or less *backwards.* To obtain an *upward* recoil, one would naturally think all that is required is a *downward* stroke, and to obtain an *upward and forward* recoil,

one would naturally conclude a *downward and backward* stroke alone is requisite. This reasoning is true of water and wings, but it is not true of air and wings.

In the first place, a natural wing, or a properly constructed artificial one, cannot be depressed either *vertically downwards, or downwards and backwards.* It will of necessity descend *downwards and forwards in a curve.* This arises from its being flexible and elastic throughout, and in especial from its being carefully graduated as regards thickness, the tip being thinner and more elastic than the root, and the posterior margin than the anterior margin.

In the second place, there is only one direction in which the wing could strike so as at once *to support and carry the bird forward.* The bird, when flying, is a body in motion. It has therefore acquired momentum. If a grouse is shot on the wing *it does not fall vertically downwards,* as Borelli and his successors assume, but *downwards and forwards.* The flat surfaces of the wings are consequently made to strike downwards and forwards, as they in this manner act as kites to the falling body, which they bear, or tend to bear, *upwards and forwards.* So much for the direction of the stroke during the descent of the wing. Let us now consider to what extent the posterior margin of the wing yields in *an upward direction* when the wing descends. Borelli does not state the exact amount. The Duke of Argyll, who agrees with Borelli that the posterior margin of the wing is elevated during the down stroke, avers that, whereas the air compressed in the hollow of the wing cannot pass through the wing owing to the closing upwards of the feathers against each other, or escape forwards because of the rigidity of the bones and of the quills in this direction, it passes backwards, and in so doing *lifts by its force the elastic ends of the feathers.* In passing backwards it communicates to the whole line of both wings a corresponding push forwards to the body of the bird. The same volume of air is thus made, in accordance with the law of action and reaction, *to sustain the bird and carry it forward.** Mr M'Gillivray observes that "to progress *in a horizontal direction* it is necessary that the downward stroke should be modified *by the elevation in a certain degree of the free extremities of the quills.*†

Marey's *Views.*—Professor Marey states that during *the down stroke* the posterior or flexible margin of the wing yields in *an upward direction,* to such an extent as to cause the under surface of the wing *to look backwards,* and make a backward angle with the horizon of 45° plus or minus according to circumstances.‡ That the posterior margin of the wing yields in a slightly upward direction during the down stroke to prevent shock, I admit. The amount of

* Reign of Law. "Good Words," February 1865, p. 128.

† History of British Birds. Lond. 1837, p. 43.

‡ Méchanisme du vol chez les insectes. Comment se fait la propulsion, by Professor E. J. Marey. Revue des Cours Scientifiques de la France et de l'Etranger for 20th March 1869, p. 254.

yielding is, however, in all cases very slight, and the little upward movement there is, is in part the result of the posterior margin of the wing rotating around the anterior margin as an axis. That the posterior margin of the wing never yields in *an upward direction* until the under surface of the pinion makes a backward angle of 45° with the horizon, as MAREY remarks, is a matter of absolute certainty. This statement admits of direct proof. If any one watches the horizontal or upward flight of a large bird, he will observe that the posterior or flexible margin of the wing never rises during the down stroke to a perceptible extent, so that *the under surface of the wing* never looks backwards. On the contrary, he will find that *the under surface of the wing* (during the down stroke) invariably *looks forwards*—the posterior margin of the wing being inclined *downwards and backwards*, the anterior one *upwards and forwards*, as shown at *c d e f*, *j k l m* of fig. 15, page 345; *h j* of fig. 38, page 361; 1, 2, 3; 4, 5, 6 of figs. 18 and 19, Plate XIV.; and *q p o* of figs. 14 and 15, Plate XIII.

The under surface of the wing, as will be seen from this account, not only *looks forwards*, but it forms a true kite with the horizon, the angles made by the kite varying at every part of the down stroke, as shown more particularly at *c, d, e, f; j, k, l, m* of fig. 15, page 345.

Professor MAREY goes on to state that not only does the posterior margin of the wing yield *in an upward direction* during the *down stroke* until the under surface of the pinion makes a backward angle of 45° with the horizon (page 415, fig. 55, *x c; a b*), but that during the *up stroke* it yields to the same extent *in an opposite direction* (*x d; a b*). The posterior flexible margin of the wing, according to MAREY, thus passes through a space of 90° every time the wing reverses its course, this space being dedicated to the mere adjusting of the planes of the wing for the purposes of flight. The planes, moreover, he asserts, are adjusted not by vital and vito-mechanical acts but by *the action of the air alone*; this operating on the under surface of the wing and forcing its posterior margin *upwards* during *the down stroke*; the air during the *up stroke* acting upon the posterior margin of the upper surface of the wing, which it forces *downwards*. MAREY thus delegates to the air, the difficult and delicate task of arranging the details of flight. The time, power, and space occupied in reversing the wing alone, according to this view, are such as to render flight impossible. That the wing does not act as stated by MAREY, may be readily proved by experiment. It may also be proved diagrammatically, as a reference to fig. 55, page 415, will show.

Let *a, b* of fig 55 represent the horizon; *m, n* the line of vibration; *x, c* the wing inclined at an upward backward angle of 45° in the act of making the down stroke, and *x, d* the wing inclined at a downward backward angle of 45° and in the act of making the up stroke. When the wing *x c* descends it will tend to dive downwards in the direction *f* (giving very little of any horizontal sup-

port); when the wing *x d* ascends it will endeavour to rise in the direction *g*, as it darts up like a kite (the body bearing it being in motion). If we take the resultant of these two forces, we have at most propulsion in the direction *a b*. This, moreover, would only hold true if the bird was as light as air. As, however, gravity tends to pull the bird downwards as it advances, the real flight of the bird, according to this explanation, would fall in a line between *b* and *f*, probably in *x h*. It could not possibly be otherwise; the wing described and figured by MAREY is in one piece, and vibrated vertically on either side of a given line. If, however, a wing in one piece is elevated and depressed in a strictly perpendicular direction, it is evident that the wing will experience a greater resistance during *the up stroke*, when it is acting *against gravity*, than during *the down stroke*, when it is acting *with gravity*. As a consequence, the bird will be more vigorously depressed during the ascent of the wing than it will be elevated during its descent. That the mechanical wing referred to by MAREY is *not a flying wing*, but a mere propelling apparatus, seems evident to himself, for he states that "the winged machine designed by him has unquestionably *not motor power enough* to *support its own weight.*"*

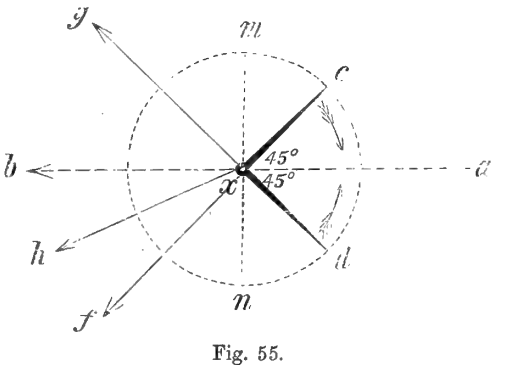


Fig. 55.

The manner in which the natural wing (and the artificial wing properly constructed and propelled) evades the resistance of the air during the up stroke, and gives continuous support and propulsion, is very remarkable. Fig. 56, page 416, will illustrate the principle. Let *a b* represent the horizon; *m n* the direction of vibration; *x s* the wing ready to make the down stroke, and *x t* the wing ready to make the up stroke. When the wing *x s* descends, the posterior margin (*s*) is screwed *downwards* and *forwards* in the direction *s, t*, the forward angle which it makes with the horizon increasing as the wing is lowered. The air is thus seized by a great variety of inclined surfaces, and as the under surface of the wing, which is a true kite, looks *upwards* and *forwards*, it tends to carry the body of the bird *upwards* and *forwards* in the direction *x w*. When the wing *x, t* makes the *up stroke*, it rotates from below upwards to prepare for the second down stroke. The wing does not, however, ascend in the direction *t, s*. On the contrary, it darts up like a true kite, which it is, in the direction *x, v*, in virtue of the reaction of the air, and because the body of the bird, to which it is attached, had a forward motion communicated to it by the wing during the down stroke. The resultant of the forces acting in the lines *x v* and *x b*, is one acting in the

* Revue des Cours Scientifiques de la France et de l'Etranger. 8vo. March 20, 1869.

direction *x w*, and if allowance be made for the operation of gravity, the flight of the bird will fall somewhere between *w* and *b*, probably in the line *x, r*. This arises from the wing acting as an eccentric—from the upper concave surface of the pinion being always directed upwards, the under concave surface downwards—from the under surface, which is a true kite, darting forwards in wave curves both during the down and up strokes, and never making a backward angle with the horizon; and lastly, from the wing employing the air under it as a fulcrum during the down stroke, the air, on its part, reacting on the under surface of the pinion, and when the proper time arrives, contributing to the elevation of the wing.

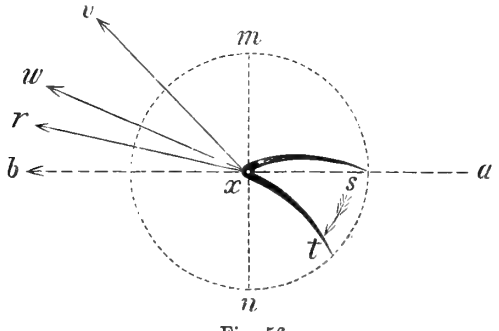


Fig. 56.

If, as Borelli and his successors believe, the posterior margin of the wing yielded to any marked extent in *an upward direction* during the *down stroke*, and more especially if it yielded to such an extent as to cause the under surface of the wing to make *a backward angle with the horizon of* 45°, one of two things would inevitably follow—either the air on which the wing depended for support and propulsion would be permitted to escape before it was utilised, or the wing would dart rapidly downward, and carry the body of the bird with it. If the posterior margin of the wing yielded in an upward direction to any marked extent during the down stroke it would be tantamount to removing the fulcrum (the air) on which the lever formed by the wing operates. The wing of the bird, as I have fully explained (see pages from 366 to 384 inclusive), acts as a kite both during *the down* and *up* strokes, the ventral aspect of the kite being always directed *forwards* (*vide* from *c* to *m* of fig. 15, page 345).

If a bird flies in a horizontal direction the angles made by the under surface of the wing with the horizon *are very slight*, but they *always look forwards*. If a bird flies upwards the angles in question are increased. In no instance, however, unless when the bird is everted and flying downwards, is the *posterior margin* of the wing *on a higher level* than the anterior one. This holds true of natural flight, and, consequently, ought to hold true of artificial flight.

With regard to the cone formed, according to Borelli, by the vertical descent of the two wings, or what, in his opinion, is the same thing, the perpendicular ascent of the air, and which is represented at *f e c* of figure 54, page 409; I think it would be more accurate to state that, instead of the two wings taken together forming *one cone*, that each wing by itself forms *two cones*.

The base of Borelli's cone (*e b c*, figure 54, p. 409), it will be remembered,

is inclined forwards in the direction of the head of the bird—the bases of the cones formed by each natural wing being, on the contrary, directed *outwards* (*vide x b d* of figure 12, page 342) and *backwards* (see *q p n* of same figure). This arises from the fact that the wing rotates upon two axes (*a b* and *c d* of figure 45, page 376); because it rotates on its root (*a* of figure 19, Plate XIV.) to form one cone (*a f e* of same figure), and because, while it is rotating on its root, it is also rotating along its anterior margin (*a b*) to form a second cone, *c h g*. The wing, in forming the cone *a f e* elevates, and in forming the cone *c h g* propels. The base of the wedge which furnishes the horizontal transference is, therefore, turned in the direction of the tail of the bird, which is just the opposite of what BORELLI maintains, the base of his wedge being turned in the direction of the head.

BORELLI, and all who have written since his time, are unanimous in affirming that the horizontal transference of the body of the bird is due to the perpendicular vibration of the wings, and to the yielding of the posterior or flexible margins of the wings in an upward direction as the wings descend. I am, however, disposed to attribute it to the fact (1st), that the wings, both when elevated and depressed, *leap forwards in curves*, those curves uniting to form a continuous waved track; (2d), to the tendency which the body of the bird has to swing forwards, in a more or less horizontal direction, when once set in motion; (3d), to the construction of the wings (they are elastic helices or screws, which twist and untwist while they vibrate, and tend to bear upwards and onwards any weight suspended from them); (4th), to the reaction of the air on the under surfaces of the wings; (5th), to the ever-varying power with which the wings are urged, this being greatest at the beginning of the down stroke, and least at the end of the up one; (6th), to the contraction of the voluntary muscles and elastic ligaments, and to the effect produced by the various inclined surfaces formed by the wings during their oscillations; (7th), to the weight of the bird —weight itself, when acting upon wings, becoming a propelling power, and so contributing to horizontal motion. This is proved by the fact that if a sea bird launches itself from a cliff with expanded motionless wings, it sails along for an incredible distance before it reaches the water.

The authors who have adopted BORELLI's plan of artificial wing, and who have indorsed his mechanical views of the wing's action most fully, are CHABRIER, STRAUS-DURCKHEIM, GIRARD, and MAREY. BORELLI's artificial wing, as a reference to fig 54, page 409, will show, consists of *a rigid rod* in front, and *a flexible sail*, composed of feathers, behind. It acts upon the air, and the air acts upon it, as occasion demands.

CHABRIER'S *Views*.—CHABRIER states that the wing has only one period of activity—that, in fact, if the wing be suddenly lowered by the depressor muscles, it is elevated solely by the reaction of the air. There is one unanswerable objec-

tion to this theory—the bats and birds, and some, if not all, the insects have distinct elevator muscles. The presence of well-developed elevator muscles implies an elevating function; and, besides, we know that the insect, bat, and bird can elevate their wings when they are not flying, and when, consequently, no reaction of the air is induced (pages 364, 365, 395, 396, and 397).

Straus-Durckheim's *Views.*—Durckheim believes that the insect abstracts from the air by means of *the inclined plane* a component force (composant) which it employs *to support* and *direct* itself. In his Theology of Nature he describes a schematic wing as follows:—It consists of *a rigid ribbing* in front, and *a flexible sail* behind. A membrane so constructed will, according to him, be fit for flight. It will suffice if such a sail *elevates* and *lowers* itself successively. It will, of its own accord, dispose itself as an inclined plane, *and receiving obliquely the reaction of the air,* it transfers *into tractile force* a part of the *vertical impulsion it has received.* These two parts of the wing are moreover equally indispensable to each other. If we compare the schematic wing of Durckheim with that of Borelli they will be found to be identical, both as regards their construction and the manner of their application.

Marey's *Views continued.*—Professor Marey, so late as 1869, repeats Borelli's arguments and views with very trifling alterations. Marey describes two artificial wings, the one composed of a *rigid rod* and *sail*—the rod representing *the stiff anterior margin* of the wing; the sail, which is made of paper bordered with card board, *the flexible posterior portion.* The other wing consists of a *rigid nervure* in front and behind of thin parchment which supports *fine rods of steel.* He states, that if the wing only elevates and depresses itself, "*the resistance of the air* is sufficient to produce all the other movements. In effect the wing of an insect has not the power of equal resistance in every part. On the anterior margin the extended nervures make it *rigid,* while behind it is fine and *flexible.* During the vigorous depression of the wing the nervure has the power of *remaining rigid,* whereas the *flexible portion,* being pushed in *an upward direction* on account of the resistance it experiences from the air, *assumes an oblique position* which causes the upper surface of the wing *to look forwards.*" The reverse of this takes place during the elevation of the wing—the resistance of the air from above causing the upper surface of the wing *to look backwards.* . . . "At first the plane of the wing is parallel with the body of the animal. It lowers itself—the *front part* of the wing *strongly resists,* the sail which follows it *being flexible yields.* Carried by the ribbing (the anterior margin of the wing) which lowers itself, the sail or posterior margin of the wing being raised meanwhile by the air, which sets it straight again, the sail will take an intermediate position, and *incline itself about* 45° plus or minus according to circumstances."

"The wing continues its movements of depression inclined to the horizon, but

the impulse of the air which continues its effect, and naturally acts upon the surface which it strikes, has the power of resolving itself into two forces, *a vertical* and *a horizontal force*, the first suffices *to raise* the animal, the second to *move it along*."*

I have already adverted at considerable length (pages 413, 414, and 415) to the movements and peculiarities of Professor MAREY's artificial wing, and need not again return to it. I will only observe, in passing, that it is not a little curious that BORELLI's artificial wing should have been reproduced at a distance of nearly two centuries.

The Author's Views:—his Method of Constructing and Applying Artificial Wings as Contradistinguished from that of BORELLI, CHABRIER, DURCKHEIM, MAREY, *&c.*—The artificial wings which I have been in the habit of making for several years differ from those recommended by BORELLI, DURCKHEIM, and MAREY in four essential points :—

1st, The mode of construction.

2d, The manner in which they are applied to the air.

3d, The nature of the power employed.

4th, The necessity of adopting certain elastic substances at the root of the wing if in one piece, and at the root and in the body of the wing if in several pieces.

And, first, as to the manner of construction.

BORELLI, DURCKHEIM, and MAREY maintain that *the anterior margin of the wing* should be *rigid;* I, on the other hand, believe that no part of the wing whatever should be rigid, *not even the anterior margin,* and that the pinion should be flexible and elastic throughout.

That the anterior margin of the wing should not be composed of a rigid rod

* Compare MAREY's description with that of BORELLI, a translation of which I subjoin. "Let a bird be suspended in the air with its wings expanded, and first let the under surfaces (of the wings) be struck by the air ascending perpendicularly to the horizon with such a force that the bird gliding down is prevented from falling: I say that it (the bird) will be impelled with a horizontal forward motion, because the two osseous rods of the wings are able, owing to the strength of the muscles, and because of their hardness, *to resist the force of the air*, and therefore to retain the same form (literally extent, expansion), but the total breadth of the fan of each wing *yields to the impulse of the air* when the flexible feathers are permitted to rotate around the "*manubria*" or osseous axis, and hence it is necessary that the extremities of the wings approximate each other: wherefore the wings acquire the form of a wedge whose point is directed towards the tail of the bird, but whose surfaces are compressed on either side by the ascending air in such a manner that it is driven out in the direction of its base. Since, however, the wedge formed by the wings cannot move forward unless it carry the body of the bird along with it, it is evident that it (the wedge) gives place to the air impelling it, and therefore the bird flies forward in a horizontal direction. But now let the substratum of still air be struck by the fans (feathers) of the wings with a motion perpendicular to the horizon. Since the fans and sails of the wings acquire the form of a wedge, the point of which is turned towards the tail (of the bird), and since they suffer the same force and compression from the air, whether the vibrating wings strike the undisturbed air beneath, or whether, on the other hand, the expanded wings (the osseous axis remaining rigid) receive the percussion of the ascending air; in either case the *flexible feathers yield to the impulse,* and hence approximate each other, and thus the bird moves in *a forward direction.*"—*De Motu Animalium*, pars prima, prop. 196, 1685.

may, I think, be demonstrated in a variety of ways. If a rigid rod be made to vibrate by the hand the vibration is not smooth and continuous; on the contrary, it is irregular and jerky, and characterised by two halts or pauses (dead points), the one occurring at the end of the *up stroke*, the other at the end of the *down stroke*. This mechanical impediment is followed by serious consequences as far as power and speed are concerned—the slowing of the wing at the end of the down and up strokes involving a great expenditure of power and a disastrous waste of time. The wing, to be effective as an elevating and propelling organ, should have no dead points, and should be characterised by a rapid winnowing or fanning motion. It should reverse and reciprocate with the utmost steadiness and smoothness—in fact, the motions should appear as continuous as those of a fly-wheel in rapid motion : they are so in the insect.

To obviate the difficulty in question, it is necessary, in my opinion, to employ *a tapering elastic rod* or *series of rods* bound together for the anterior margin of the wing.

If a longitudinal section of bamboo cane, 10 feet in length, and 1 inch in breadth (*vide* fig. 57, p. 421), be taken by the extremity and made to vibrate, it will be found that a wavy serpentine motion is produced, the waves being greatest when the vibration is slowest (fig. 58, p. 421), and least when it is most rapid (fig. 59, p. 421). It will further be found that at the extremity of the section where the impulse is communicated there is *a steady reciprocating movement devoid of dead points*. The continuous movement in question is no doubt due to the fact that the different portions of the reed reverse at different periods—the undulations induced being to an interrupted or vibratory movement very much what the continuous play of a fly-wheel is to a rotatory motion.

The Wave Wing of the Author.—If a similar reed has added to it, tapering rods of whalebone, which radiate in an outward direction to the extent of a foot or so, and the whalebones be covered by a thin sheet of india-rubber, an artificial wing, resembling the natural one in all its essential points, is at once produced (*vide* fig. 60, p. 421). I propose to designate this wing, from the peculiarities of its movements, *the wave wing* (fig. 61, p. 421). If the wing referred to (fig. 61) be made to vibrate at its root, a series of longitudinal (*c d e*) and transverse (*f g h*) waves are at once produced, the one series running in the direction of *the length of the wing*, the other in the direction of *its breadth* (*vide* p. 330). This wing further *twists* and *untwists*, figure of 8 fashion, during the down and up strokes, as shown at figure 62, page 423 (compare with figure 2, p. 336). There is, moreover, a continuous play of the wing, the down stroke gliding into the up one, and *vice versa*, which clearly shows that the down and up strokes are parts of one whole, and that neither is perfect without the other.

This wing is endowed with the very remarkable property that it will fly in any direction, demonstrating more or less clearly that flight is essentially a pro-

gressive movement, *i.e.*, a horizontal rather than a vertical movement. Thus, if the anterior or thick margin of the wing be directed upwards, and the angle which the under surface of the wing makes with the horizon be something like

Fig. 57.*

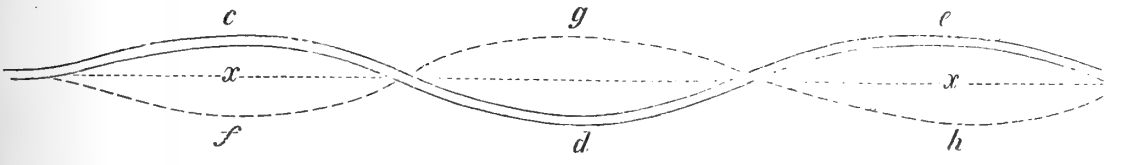


Fig. 58.†

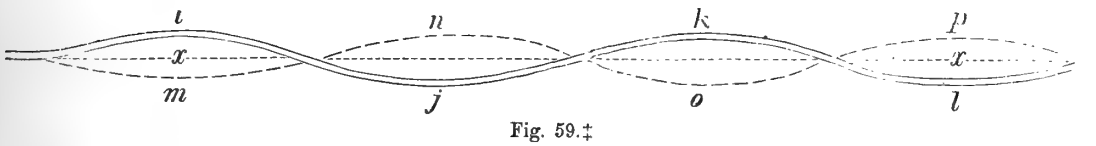


Fig. 59.‡

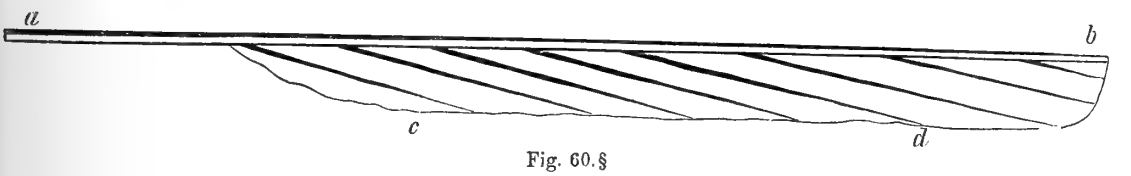


Fig. 60.§

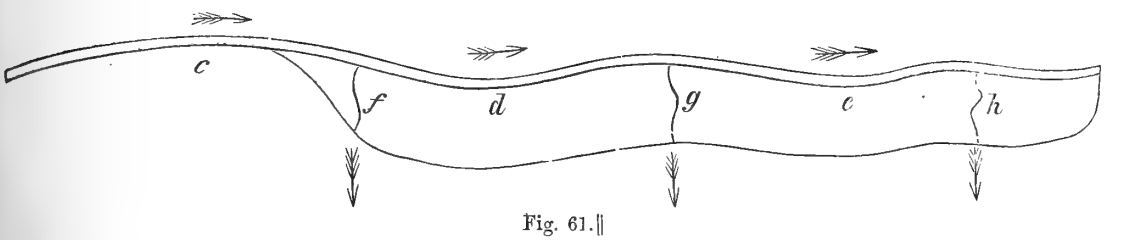


Fig. 61.‖

45°, the wing will, when made to vibrate by the hand, fly with an undulating motion *in an upward direction,* like a pigeon to its dovecot. If the under surface of the wing makes no angle, or a very small angle, with the horizon, it will

* Fig. 57 represents a longitudinal section of bamboo reed 10 feet long, and 1 inch wide.

† Fig. 58. The appearance presented by the same reed when made to vibrate by the hand. The reed vibrates on either side of a given line (x x), and appears as if in two places at the same time, viz., c and f, g and d, e and h. It is thus during its vibration thrown into figures of 8 or opposite curves.

‡ Fig. 59. The appearance presented by the same reed when made to vibrate more rapidly. In this case the waves made by the reed are less in size, but more numerous than in fig. 58. The reed vibrates alternately on either side of the line x x, being now at i now at m, now at n now at j, now at k now at o, now at p now at l. This reed, when made to vibrate by the hand, has no dead points, a circumstance due to the fact that no two parts of it reverse or change their curves at precisely the same instant. It is because of this curious reciprocating motion that the wing can seize and disengage itself from the air with such rapidity.

§ Fig. 60. The same reed with a flexible elastic curtain or fringe added to it. The curtain consists of tapering whalebone rods covered with a thin layer of india-rubber. a b anterior margin of wing. c d posterior ditto.

‖ Fig. 61 gives the appearance presented by the artificial wing (fig. 60) when made to vibrate by the hand. It is thrown into longitudinal and transverse waves. The longitudinal waves are represented by the arrows c d e, and the transverse by the arrows f g h. A wing constructed on this principle gives a continuous elevating and propelling power. It developes figure of 8 curves during its action in longitudinal, transverse, and oblique directions. It literally floats upon the air. It has no dead points—is vibrated with amazingly little power, and has apparently no slip. It can fly in an upward, downward, or horizontal direction by merely altering its angle of inclination to the horizon. It must be applied to the air by an irregular motion—the movement being most sudden and vigorous always at the beginning of the down stroke.

dart forward in a series of curves in a *horizontal direction*, like a crow in rapid horizontal flight. If the angle made by the under surface of the wing be reversed, so that the thick margin of the wing be directed downwards, the wing will describe a waved track, and *fly downwards*, as a sparrow from a house-top or from a tree. In all those movements progression is a necessity. The movements are continuous gliding *forward movements*. There is no halt or pause between the strokes, and if the angle which the under surface of the wing makes with the horizon be properly regulated, the amount of steady tractile and buoying power developed is truly astonishing. This form of wing, which may be regarded as the realisation of the figure of 8 theory of flight, elevates and propels both during the down and up strokes, and its working is accompanied with almost no slip. It seems literally to float upon the air. No wing that is rigid in the anterior margin can twist and untwist during its action, and produce the figure of 8 curves generated by the living wing. To produce the curves in question, the wing must be flexible, elastic, and capable of change of form in all its parts. The curves made by the artificial wing, as has been stated (p. 420), are largest when the vibration is slow, and least when it is quick. In like manner, the air is thrown into large waves by the slow movement of a large wing, and into small waves by the rapid movement of a smaller wing. The size of the *wing curves* and *air waves* bear a fixed relation to each other, and both are dependent on the rapidity with which the wing is made to vibrate. This is proved by the fact that insects, in order to fly, require, as a rule, to drive their small wings with immense velocity. It is further proved by the fact that the small humming bird, in order to keep itself stationary before a flower, requires to oscillate its tiny wings with great rapidity, whereas the large humming bird (*Patagona gigas*), as was pointed out by DARWIN, can attain the same object by flapping its large wings with a very slow and powerful movement. In the larger birds the movements are slowed in proportion to the size, and more especially in proportion to the length of the wing, the cranes and vultures moving the wings very leisurely, and the large oceanic birds dispensing in a great measure with the flapping of the wings, and trusting for progression and support to the wings in the expanded position.

This leads me to conclude that very large wings may be driven with a comparatively slow motion, a matter of some inportance in artificial flight secured by the flapping of wings.

How to Construct an Artificial Wave Wing on the Insect Type.—The following appear to me to be essential features in the construction of an artificial wing :—

The wing should be of a generally triangular shape.

It should taper from the root towards the tip, and from the anterior margin in the direction of the posterior margin.

It should be convex above and concave below, and slightly twisted upon itself.

It should be flexible and elastic throughout, and should twist and untwist during its vibration, to produce figure of 8 curves along its margins and throughout its substance.

Such a wing is represented at figure 62.

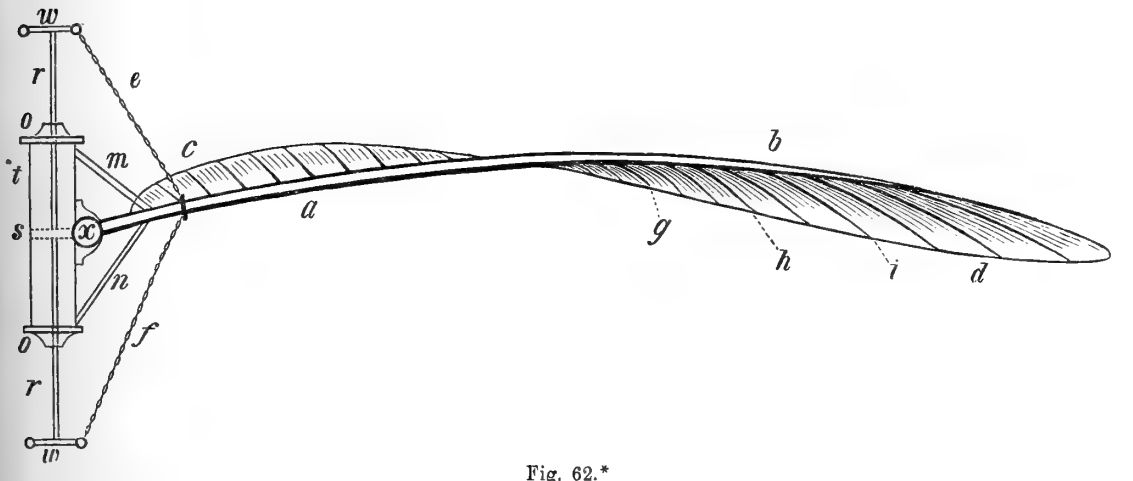


Fig. 62.*

If the wing is in more than one piece, joints and springs require to be added to the body of the pinion.

In making a wing in one piece on the model of the insect wing, such as that shown at figure 62, I employ one or more tapering elastic reeds, which arch from above downwards (*a b*) for the anterior margin. To this I add tapering elastic reeds, which radiate towards the tip of the wing, and which also arch from above downwards (*g, h, i*). These latter are so arranged that they confer *a certain amount of spirality* upon the wing, the anterior (*a b*) and posterior (*c d*) margins being arranged in different planes, so that they appear to cross each other. I then add the covering of the wing, which may consist of india-rubber, silk, tracing cloth, linen, or any similar substance.

If the wing is large, I employ steel tubes, bent to the proper shape. In some cases I secure additional strength by adding to the oblique ribs or stays (*g h i* of figure 62) a series of very oblique stays, and another series of cross stays, as shown at *m* and *a, n, o, p, q* of fig. 63, page 424.

* Fig. 62. Elastic spiral wing, which twists and untwists during its action, to form *a mobile helix or screw*. This wing is made to vibrate by a direct piston action, and by a slight adjustment can be propelled vertically, horizontally, or at any degree of obliquity.

a, b, Anterior margin of wing, to which the neuræ or ribs are affixed. *c, d*, Posterior margin of wing crossing anterior one. *x*, Ball and socket joint at root of wing, the wing being attached to the side of the cylinder by the socket. *t*, Cylinder. *r, r*, Piston, with cross heads (*w, w*) and piston head (*s*). *o, o*, Stuffing boxes. *e, f*, Driving chains. *m*, Superior elastic band, which assists in elevating the wing. *n*, Inferior elastic band, which antagonises *m*. The alternate stretching of the superior and inferior elastic bands contributes to the continuous play of the wing, by preventing dead points at the end of the down and up strokes.

This form of wing is made to oscillate upon two centres (*x* and *l* of fig. 63), to bring out the peculiar eccentric action of the pinion.

If I wish to produce a very delicate light wing, I do so by selecting a fine tapering elastic reed, as represented at *a b* of figure 64, p. 425.

To this I add successive layers (*i, h, g, f, e,*) of some flexible material, such as parchment, buckram, tracing cloth, or even paper. As the layers overlap each other, it follows that there are five layers at the anterior margin (*a b*), and only one at the posterior (*c d*). This form of wing is not twisted upon itself structurally, but it twists and untwists, and becomes a true screw during its action.

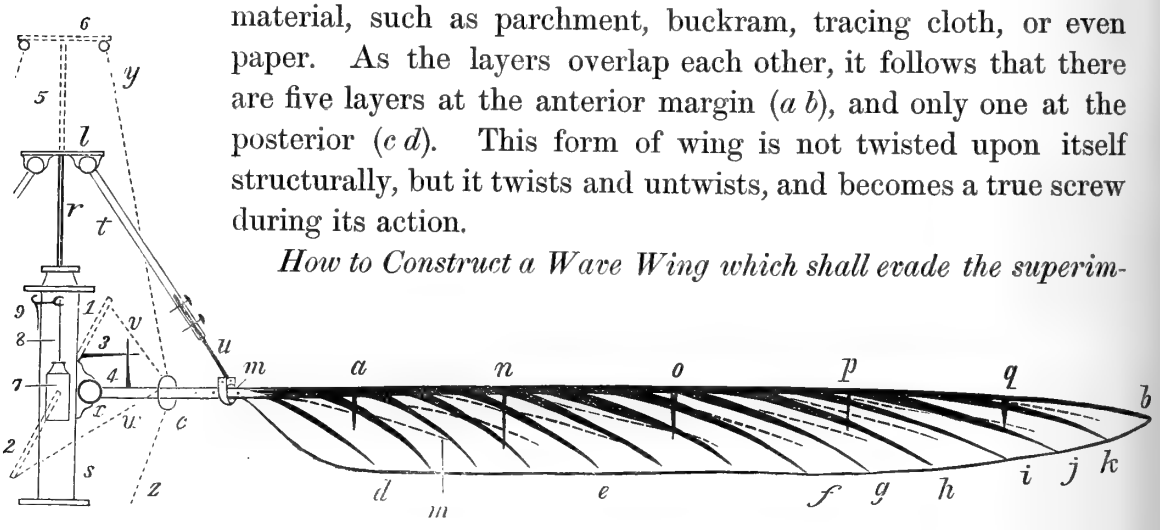


Fig. 63.*

How to Construct a Wave Wing which shall evade the superimposed Air during the Up Stroke.—To construct a wing which shall elude the air during the up stroke, it is necessary to make it valvular, as shown at fig. 65, p. 425.

* Fig. 63. *Artificial Wing with Driving Apparatus.*

a b, Strong elastic rod, which tapers towards the tip of the wing.

d, e, f, g, h, i, j, k, Tapering curved reeds, which run obliquelyf rom the anterior to the posterior margin of the wing, and whch radiate towards the tip.

m, Similar curved reeds, which run still more obliquely.

a, n, o, p, q, Tapering curved reeds, which run from the anterior margin of the wing, and at right angles to it. These support the two sets of oblique reeds, and give additional strength to the anterior margin.

x, Ball and socket joint, by which the root of the wing is attached to the cylinder.

s, Steam cylinder.

r, Piston, with cross bar, with which driving gear (*t*) is connected by ball and socket joint (*l*), and by a hinge joint (*m*). The hinge joint is mounted on a tube, through which the root of the wing passes, and within which it can rotate in the direction of its length (long axis). The hinge joint and the tube on which it is mounted can be moved *out and in* upon the root of the wing, and fixed by the aid of pins. By this means the range of the wing, *i.e.*, the length of the stroke, can be increased or diminished. The driving gear is arranged on a similar principle. Thus, by causing the portion marked *u* to move within the tube (*t*) in an upward direction, the wing vibrates on a higher level than natural. If, on the other hand, the portion marked *u* be moved in a downward direction, the wing vibrates on a lower level. The range of the wing and its arc of vibration are thus easily regulated.

1, 2, Cross bar attached to steam chest (7) and to cylinder (*s*). To this anterior (*v*) and posterior (*w*) elastic bands are affixed. Those elastic bands (anterior and posterior) are bound to the anterior and posterior portions of the ring *c*; *y*, superior elastic band ; *z*, inferior ditto.

3, 4, Steel springs running at right angles to each other, and attached respectively to the cross bar and the root of the wing anteriorly. They come in contact when the wing descends, and prevent the anterior margin of the wing from dipping, *i.e.*, from diving downwards during the down stroke. This result is also secured by inserting the superior elastic band (*y*) into the upper and anterior portion of the ring *c*. Indeed, by employing a cross bar or lever, similar to that marked 4, in place of the ring *c*, the amount of rotation of the posterior margin round the anterior one can be regulated both during the down and up strokes. If the superior elastic band (*y*) be moved towards the tip of the lever, the degree of rotation is increased ; if it be moved towards the root of the lever, it is diminished.

5. Rod fixed to posterior of cylinder, and bearing cross bar (6), to which the superior elastic band (*y*) is attached.

NOTE.—In the present arrangement the steam chest (7) and valve occupy the centre of the cylinder *posteriorly*, the valve being opened and closed by the aid of an idle rod (furnished with two kickers), which passes through a loop projecting from the piston *anteriorly*. The idle rod and kickers move a small lever (9), which in turn moves the spindle (8), to which the steam valve is attached. The cylinder is fixed to the top of the boiler, and the ports for the admission of steam to the cylinder are unequal in size, the *upper port* being larger than the *under one*. Unequal quantities of steam are thus admitted to the top and bottom of the cylinder respectively, the greater quantity admitted to the top causing the wing to descend much more quickly than it ascends. From the above figure it will be seen that the movements of the wing are communicated directly from the *piston*, a great saving in weight and power being thus effected.

This wing, as the figure indicates, is composed of *numerous narrow segments* (*f f f, g g g*), so arranged that the air, when the wing is made to vibrate, opens or separates them at the beginning of the up stroke, and closes or brings them together at the beginning of the down stroke.

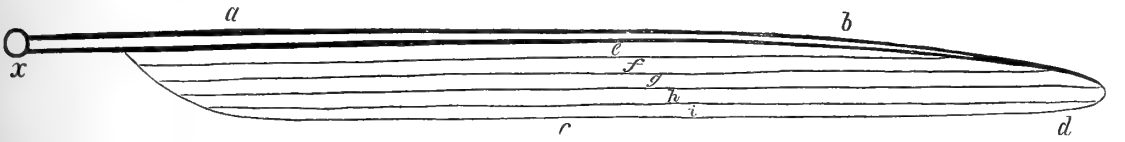


Fig. 64.*

The time and power required for opening and closing the segments is comparatively trifling, owing to their extreme narrowness and extreme lightness. The space, moreover, through which they pass in performing their valvular

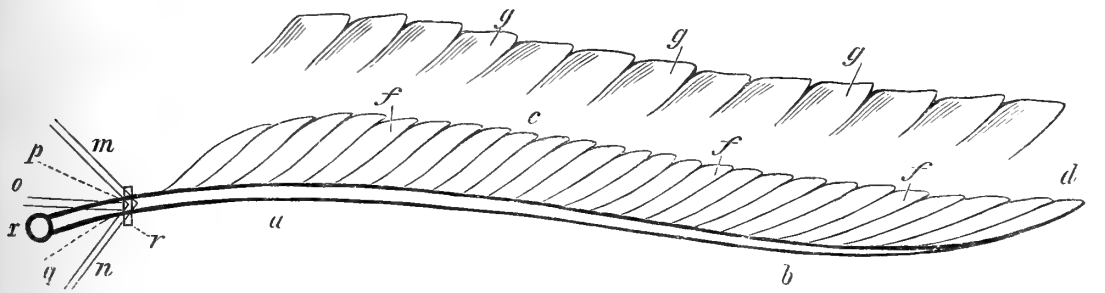


Fig. 65.†

action is exceedingly small. The wing under observation is flexible and elastic throughout, and resembles in its general features the other wings described.

I have also constructed a wing which is self-acting in another sense. This consisted of two parts—the one part being made of an elastic reed, which tapered towards its extremity, the other of a flexible sail. To the reed, which corresponded to the anterior margin of the wing, delicate tapering reeds were fixed at right angles, the principal and subordinate reeds being arranged on the same plane. The flexible sail was attached to the under surface of the principal reed, and was stiffer at its insertion than towards its free margin. When the wing was made to ascend, the sail, because of the pressure exercised upon its upper surface by the air, assumed a very oblique position, so that the resistance experienced by it during the *up stroke* was very slight. When, however, the wing descended, the sail instantly flapped in an upward direction, the

* Fig. 64. *x*, Ball and socket joint at root of wing. *a*, *b*, Anterior margin of wing. *c*, *d*, Posterior margin of wing. *i*, Portion of wing composed of one layer of flexible material. *h*, Portion of wing composed of two layers. *g*, Portion of wing composed of three layers. *f*, Portion of wing composed of four layers. *e*, Portion of wing composed of five layers.

† Fig. 65. Flexible *valvular wing* with India-rubber springs attached to its root.

a, *b*, Anterior margin of wing, tapering and elastic. *c*, *d*, Posterior margin of wing, elastic. *f*, *f*, *f*, Segments which open during the up stroke and close during the down, after the manner of valves. These are very narrow, and open and close instantly. *g*, *g*, *g*, The same segments magnified. *x*, Universal joint. *m*, Superior elastic band. *n*, Ditto inferior. *o*, Ditto anterior. *p*, *q*, Ditto oblique. *r*, Ring into which the elastic bands are fixed.

subordinate reeds never permitting its posterior or free margin to rise above its anterior or fixed margin. The under surface of the wing consequently descended so as to present a flat surface to the earth. It experienced much resistance from the air during the *down stroke,* the amount of buoyancy thus furnished being very considerable. The above form of wing is more effective during the down stroke than during the up. It, however, elevates and propels during both, the forward travel being greatest during the down stroke.

Compound Wave Wing.—In order to render the movements of the wing as simple as possible, I was induced to devise a form of pinion, which for the sake of distinction I shall designate the *Compound Wave Wing.* This wing consists of two wave wings united at their roots, as represented at *b, c,* (A, A′) of fig. 66. It is attached by its centre to the head of the piston by a compound joint

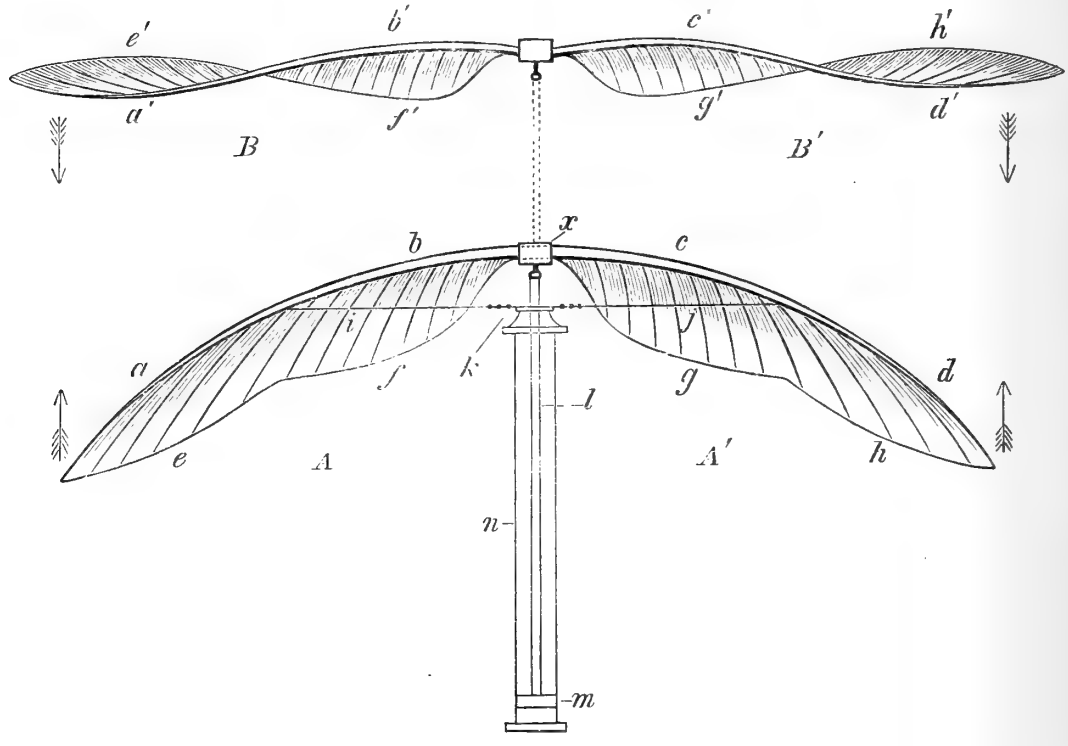


Fig. 66.

(*x*), which enables it to move in a circle, and to rotate along its anterior margin (*a, b, c, d,* A, A′) in the direction of its length. The circular motion is for steering purposes only. The wing rises and falls with every stroke of the piston, and the movements of the piston are quickened during the down stroke, and slowed during the up one (*vide* note to fig. 63, p. 424, also pp. 432 and 433).

During the up stroke of the piston the wing is very decidedly convex on its upper surface (*a, b, c, d,* A, A′), its under surface being deeply concave and inclined obliquely upwards and forwards. It thus evades the air during the up stroke.

During the down stroke of the piston the wing is flattened out in every direction, and its extremities twisted in such a manner as to form two screws, as shown at *a′ b′ c′ d′*; *e′ f′ g′ h′*; B, B′ of figure. The active area of the wing is by this means augmented, so that it seizes the air with great avidity during the down stroke. The area of the wing may be still further increased and diminished during the down and up strokes by adding joints to the body of the wing on the principle recommended at pages 428, 429, 430, and 431, figs. 67, 68, and 69. The degree of convexity given to the upper surface of the wing can be increased or diminished at pleasure by causing a cord (*i j*; A, A′) and elastic band (*k*) to extend between two points, which may vary according to circumstances. The wing is supplied with vertical springs, which assist in slowing and reversing it towards the end of the down and up strokes, and these, in conjunction with the elastic properties of the wing itself, contribute powerfully to its continued play. The compound wave wing produces the currents on which it rises. Thus during the up stroke it draws after it a current, which being met by the wing during its descent, confers additional elevating and propelling power. During the down stroke the wing in like manner draws after it a current which forms an eddy, and on this eddy the wing rises, as explained at page 438, fig. 72. The ascent of the wing is favoured by the superimposed air playing on the upper surface of the posterior margin of the organ, in such a manner as to cause the wing to assume a more and more oblique position with reference to the horizon. This change in the plane of the wing enables its upper surface to avoid the superincumbent air during the up stroke, while it confers upon its under surface a combined kite and parachute action. The compound wave wing leaps forward in a curve both during the down and up strokes, so that the wing during its vibration describes a waved track, as shown at *a, c, e, g, i* of fig. 14, page 344. The compound wave wing possesses most of the peculiarities of single wings when made to vibrate simultaneously. It forms a most admirable elevator and propeller, and has this advantage over ordinary wings, that it can be worked without injury to itself, when the machine which it is intended to elevate is resting on the ground. Two or more compound wave wings may be arranged on the same plane, or superimposed, and made to act in concert. They may also by a slight modification be made to act horizontally instead of vertically. The length of the stroke of the compound wave wing is determined in part, though not entirely, by the stroke of the piston—the extremities of the wing, because of their elasticity, moving through a greater space than the centre of the wing. By fixing the wing to the head of the piston all gearing apparatus is avoided, and the number of joints and working points reduced—a matter of no small importance when it is desirable to conserve the motor power and keep down the weight.

How to Construct a Wave Wing on the Bat and Bird type.—In order to

imitate the bat and bird's wing successfully it is necessary to introduce joints: the artificial wing, in fact, requires to be composed of several pieces, so that it will flex or fold towards the end of the down stroke, and open out or expand towards the end of the up stroke. This is requisite for several reasons. In the first place, the wing of the bat and bird is made to vibrate in a much more vertical direction (figs. 5 and 6, Plate XI., figs. 18 and 19, Plate XIV.,) than that of the insect (fig. 4, Plate XI.) They have therefore to contend directly with the resistance furnished by the superimposed air. As a consequence, the wing in such of the bats and birds as do not sail or skim must be folded more or less completely during the up stroke to diminish the wing area, so as to elude the resistance offered by the air when the wing is being elevated. It is for this reason too, that in the bird the rowing feathers open up or separate during the up stroke. As the wings of the bat and bird afford comparatively little support during the up stroke, it follows that the wing area must be increased to its utmost during the down stroke. But for the folding or closing of the wing towards the termination of the down stroke, the downward passage of the pinion, as I have repeatedly satisfied myself by experiment, could not be suddenly arrested and a new upward passage commenced. In other words, the wing could not be reversed. At the beginning of the down stroke the wing is a long lever, and acts as such, (*vide c d* of fig. 6, Plate XI.) It is depressed with extreme energy and acquires during its descent a degree of momentum which could not possibly be checked if the wing was not suddenly flexed and instantly converted from a *long* into a *short* lever, (*vide a b* of fig. 6, Plate XI.) The wing is therefore by this very simple contrivance, not only robbed of its momentum, but what is quite as important, it is prepared for making the up or return stroke. If the wing of a gull just dead be taken, and the air winnowed by it in a more or less vertical direction, it will be found to fly open and to extend itself during the down stroke, and to fold up or close during the up stroke. The quicker the wing is made to vibrate, the more admirable is the result. Indeed, the gull's wing, when made to oscillate as recommended, reverses perfectly and has no dead points. It moreover furnishes a steady persistent buoying power which is quite remarkable when the limited dimensions of the pinion are taken into account.

To construct a bat or bird's wing, I take a tapering flexible reed, and cut it into three pieces, each piece varying in length. These I bend to the shape required as shown at *a*, *d*, and *g* of figs. 67 and 68, page 429.

The shortest and thickest piece (*a*) I furnish with a ball and socket joint at one end (*x*), and a hinge joint (*b*) at the other. The second shortest and strongest piece (*d*) I supply with a hinge joint at either end (*b* and *e*); and the third piece, which is the longest and weakest, I provide with a hinge joint at its thicker or proximal end (*e*). When the three pieces are joined together as

shown in the figures, I apply to each of the pieces at intervals tapering elastic curved reeds (*o, p, q,* fig. 68), the reeds radiating in the direction of the tip of the wing, and in such a manner as to confer a certain degree of spirality upon it. I then cause elastic substances (*h i, j k,* of figs. 67 and 68,) to extend between the pieces (*a, d, g*). The covering is then added in one piece if a bat's wing is desired, and in several (see valvular wing, fig. 65, page 425,) if the more highly differentiated wing of the bird is aimed at.

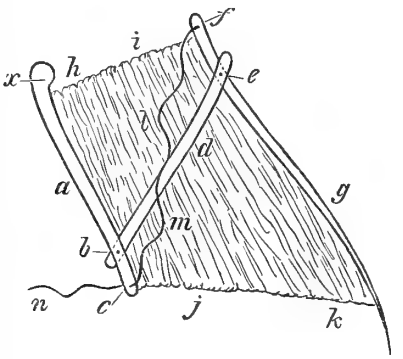


Fig. 67.*

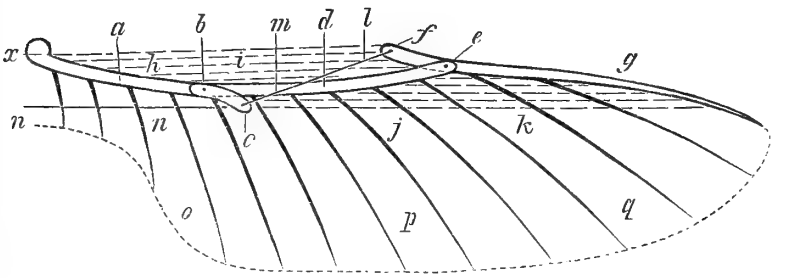


Fig. 68.

The covering may consist of a thin layer of india-rubber, silk, linen, or any other flexible material.

To the inner extremity of the distal reed (*f*) I attach a cord or wire, and this cord or wire (*l, m, n,*) I pass through an aperture in the outer extremity (*c*) of the proximal reed. I then fix the free end of the cord to a loop in the cylinder (*vide q* of fig. 69, p. 430), from which the wing receives its movements by a direct piston action.

The arrangement is represented at fig. 69, page 430.

When the wing is elevated from B to A (fig. 69) by the direct action of the

* Figures 67 and 68. Wing made to close or fold during the up stroke, and to open out or expand during the down stroke.

At fig. 67, the wing is represented as folded upon itself. *x* Universal joint at root of wing. *a* Proximal portion of wing. *d* Central portion of wing. *g* Distal portion of wing. *b* Joint uniting proximal and central portions of wing. *e* Joint uniting central and distal portions. *h i, j k* Sheet of elastic substance which when contracted as represented, tends to approximate the proximal (*a*), central (*d*), and distal (*g*), portions of wing. *l, m, n* A cord or wire fixed at *f* and running through an aperture at *c*. If this cord be rendered taught (provided the root of the wing (*x*) is fixed in its socket), it causes the proximal (*a*), central (*d*), and distal (*g*) portions of the wing suddenly to dart out and arrange themselves in a nearly straight line as shown at *a, d, g* of fig. 68.

At fig. 68 the wing is represented as fully extended or spread out. The lettering is the same as in fig. 67. *o, p, q* Ribs or stays of the wing which support the covering or curtain.

piston (*r r*), and the gearing apparatus (*y z*), it is likewise extended or spread out, the mere elevation of the piston rendering the cord or wire (*l, n,*) taught—

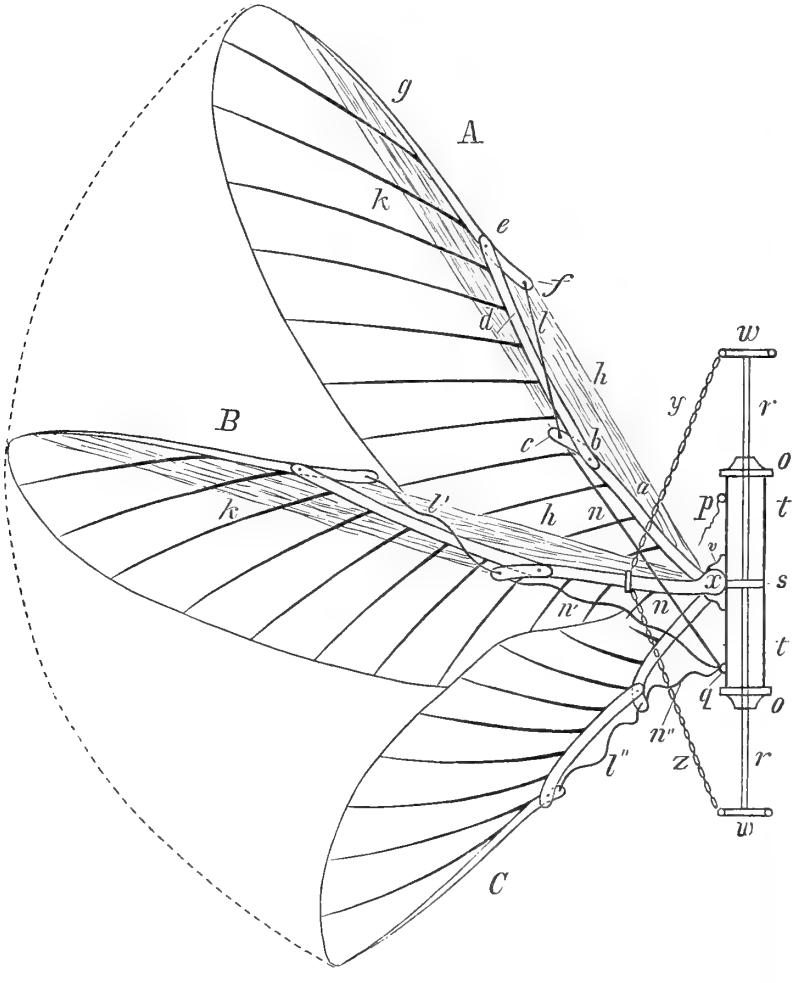


Fig. 69.*

the taughtness of the cord causing the different parts of the wing to fly outwards, while it at the same time puts the elastic substances (*h k*) on the stretch.

* Fig. 69. Wing which folds upon itself during the up stroke, and expands during the down one, made to vibrate by a direct piston action. At A the wing is fully expanded and in the act of commencing the down stroke. At B the wing is at mid stroke and very slightly folded. At C the wing is fully folded, and ready to begin the up stroke. It is thus that the wing acts as a *long lever* at the beginning of the down stroke, and a *short one* at the beginning of the up one. Compare with figs. 18 and 19, Plate XIV., and also with figs. 9, 10, and 11, Plate XII. The lettering of the wing in the present fig. is the same as in fig. 68, p. 429.

x Universal joint at root of wing received into cup-shaped cavity (*v*) of cylinder (*t*).

a Proximal, *d* central, and *g* distal portions of wing.

b, *e*, Joints which unite the three portions of the wing to each other.

f, *q*, Points to which the cord or wire of wing is fixed.

c, Aperture through which cord or wire of wing glides as the wing ascends and descends. When the piston ascends it elevates the wing by its gearing *y z*. It also renders the cord *l n* taught, the cord in its turn extending the wing (A) and the elastic substance *h k*. When the piston descends to mid stroke the wing is very slightly folded (B) and the cord *l' n'* somewhat relaxed. When the piston has quite descended the cord *l'' n''* is very much relaxed, and as a consequence the elastic substance extending between the different portions of the wing has contracted, the wing being thereby folded upon itself (*C*). The elastic substance may be dispensed with, if a strong elastic cord be employed instead of the non-elastic one *l*, *n*. If two cords be fixed to two points on the cylinder as at *p* and *q*, and the one cord be passed on the upper surface of the wing, and the remaining one on the under surface, the wing will be under control during the whole of the down and up strokes, the one cord extending the wing, the other flexing it.

t, *t*, Cylinder. *o*, *o*, Stuffing boxes. *r r*, Piston. *w*, *w*, Cross heads for driving gear. *y z* Driving gear. *s* Piston head. *v*, Cup-shaped cavity for receiving root of wing.

The instant the wing begins to descend, the cord is more or less relaxed, and a struggle ensues between the air, which endeavours to keep the wing open, and the elastic substances (*h k*) which endeavour to close it. If the wing is very forcibly depressed, it is kept open till quite near the end of the down stroke, when the elastic bands close it (C), destroy its momentum, and prepare it for the up stroke. This form of wing acts as a short lever (C) during the up stroke, and a long one (A) during the down stroke. It therefore eludes the superimposed air to a great extent when it is being elevated. If it is thought desirable to differentiate the wing still further in imitation of the bird's wing, it is only necessary to add a series of segments similar to those represented at fig. 65, page 425, these segments representing the individual rowing feathers. What especially struck me on analysing the movements of the artificial bat and bird's wing, was the fact, that during their vibrations figure of 8 curves were developed along their anterior and posterior margins similar to those found in the living wings; that the under surfaces of the pinions made various angles of inclination with the horizon analogous to those made by the natural wings; these changes being induced in a great measure independently of the air, in virtue apparently of inherent structural peculiarities. This I regard as a very remarkable circumstance, and one well worthy the attention of the physiologist and mechanician.

How to apply Artificial Wings to the Air.—Borelli, Durckheim, Marey, and all the writers with which I am acquainted, assert that the wing should be made to vibrate *vertically*. I believe that if the wing be in one piece it should be made to vibrate *obliquely and more or less horizontally*. If, however, the wing be made to vibrate *vertically*, it is necessary to supply it with a ball and socket joint, and with springs at its root (*m n* of fig. 62, page 423), to enable it *to leap forward in a curve* when it descends, and in another and *opposite curve* when it ascends (*vide a, c, e, g, i* of fig. 14, page 344). This arrangement practically converts the vertical vibration into *an oblique one*. If this plan be not adopted the wing is apt to foul at its tip. In applying the wing to the air it ought to have a figure of 8 movement communicated to it either directly or indirectly. It is a peculiarity of the artificial wing properly constructed, (as it is of the natural wing), to *twist and untwist and make figure of* 8 *curves during its action* (see *a b, c d* of fig. 62, page 423), this enabling it to seize and let go the air with wonderful rapidity, and in such a manner as to avoid dead points. If the wing be in several pieces it may be made to vibrate more vertically than a wing in one piece, from the fact that the outer half of the pinion moves forwards and backwards when the wing ascends and descends so as alternately to become a short and long lever. (Compare C with A of fig. 69, page 430), this arrangement permitting the wing to avoid the resistance experienced from the air during the up stroke, while it vigorously seizes the air during the down stroke.

If the body of a flying animal be in a horizontal position, a wing attached to it in such a manner that its under surface shall look forwards, and make an upward angle of 45° with the horizon, is in a position to be applied either vertically (figs. 5 and 6, Plate XI.), or horizontally (figs. 3, 4, 5, and 6, page 338). Such, moreover, is the conformation of the shoulder joint in insects, bats, and birds, that the wing can be applied vertically, horizontally, or at any degree of obliquity without inconvenience.* It is in this way that an insect which may begin its flight by causing its wings to make figure of eight horizontal loops (*vide* fig. 8, page 340), may gradually change the direction of the loops, and make them more and more oblique until they are nearly vertical (see fig. 13, page 342). In the beginning of such flight the insect is screwed *nearly vertically upwards;* in the middle of it, it is screwed *upwards and forwards;* whereas, towards the end of it, the insect advances in *a waved line* almost horizontally (see *q, r, s, t,* of fig. 11, page 341). The muscles of the wing are so arranged that they can propel it in a horizontal, vertical, or oblique direction. It is a matter of the utmost importance that the direction of the stroke and the angles made by the surfaces of the wing during its vibration with the horizon should be distinctly understood, as it is on these that all flying creatures depend when they seek to elude the upward resistance of the air, and secure a maximum of elevating and propelling power with a minimum of slip.

Nature of the Forces required for Propelling artificial wings.—Borelli, Durckheim, and Marey affirm that it suffices if the wing merely elevates and depresses itself by a rythmical movement in a perpendicular direction, while Chabrier is of opinion that a movement of depression only is required. All those observers agree in believing that the details of flight are due to the reaction of the air on the surface of the wing. Repeated experiment has, however, convinced me that the artificial wing must be thoroughly under control, both during the down and up strokes—the details of flight being in great measure due to the movements communicated to the wing by an intelligent agent. In order to reproduce flight by the aid of artificial wings I find it necessary to employ a power which varies in intensity at every stage of the down and up strokes. The power which I find suits best is one which is made to act very suddenly and forcibly at the beginning of the down stroke, which gradually abates in intensity until the end of the down stroke where it ceases to act in a downward direction. The power is then made to act in an upward direction, and gradually to decrease until the end of the up stroke. The force is thus applied more or less continuously, its energy being increased and diminished according to the position

* The human wrist is so formed that if a wing be held in the hand at an upward angle of 45°, the hand can apply it to the air in a vertical or horizontal direction without difficulty. This arises from the power which the hand has of moving in an upward and downward direction, and from side to side with equal facility. The hand can also rotate on its long axis, so that it virtually represents all the movements of the wing at its root.

of the wing, and the amount of resistance which it experiences from the air. The flexible and elastic nature of my peculiar form of wing (wave-wing), assisted by certain springs to be presently explained, ensure a continuous vibration where neither halts nor dead points are observable. I obtain the varying power required by a direct piston action, and by working the steam expansively (*vide* figs. 62, 63, and 69, pages 423, 424, and 430). The power employed is materially assisted, particularly during the up stroke, by the reaction of the air and the elastic structures about to be described. An artificial wing, propelled and regulated by the forces recommended, is in some respects as completely under control as the wing of the insect, bat or bird.

Necessity for supplying the root of artificial wings with elastic structures in imitation of the muscles and elastic ligaments of flying animals.—Borelli, Durckheim, and Marey, who advocate the perpendicular vibration of the wing, make no allowance, so far as I am aware, for the wing *leaping forward in curves* during *the down and up strokes.* As a consequence, the wing is jointed in their models to the frame by a simple joint which moves only in one direction, viz., from above downwards, and *vice versa.* Observation and experiment have, however, convinced me that an artificial wing, to be effective as an elevator and propeller, ought to be able to move not only in an upward and downward direction, but also in a *forward, backward,* and *oblique direction,* nay, more, that it should be free to rotate along its anterior margin *in the direction of its length:* in fact, that its movements should be universal. Thus it must be able to rise or fall, to advance or retire, to move at any degree of obliquity, and to rotate along its anterior margin. To secure the several movements in question I furnish the root of the wing with a ball and socket-joint, *i.e.*, a universal joint (see *x* of fig. 62, page 423; and *x* of fig. 63, page 424). To regulate the several movements when the wing is vibrating, and to confer on the wing the various inclined surfaces requisite for flight, as well as to delegate as little as possible to the air, I employ a cross system of elastic bands. These bands vary in length, strength, and direction, and are attached to the anterior margin of the wing (near its root), and to the cylinder (or a rod extending from the cylinder) of the model respectively (*vide m, n* of fig. 62, page 423). The principal bands are four in number: a superior (fig. 63, page 424, *y*), inferior (*z*), anterior (*v*), and posterior (*w*). The superior band extends between a rod proceeding from the upper part of the cylinder (5) of the model, and the upper surface of the anterior margin (*a, b,*) of the wing; the inferior band (*z*), extending between the under part of the cylinder or boiler and the inferior surface of the anterior margin (*d, e, f,*) of the pinion. The anterior (*v*), and posterior (*w*), bands are attached to the anterior and posterior portions of the wing and to rods extending from the centre of the anterior and posterior portions of the cylinder. Oblique bands are added (*vide p, q* of fig. 65, page 425), and these are so arranged that they give to the wing

during its descent and ascent the precise angles made by the wing with the horizon in natural flight. The superior bands are stronger than the inferior ones, and are put upon the stretch during the down stroke. They thus help the wing over the dead point at the end of the down stroke, and assist, in conjunction with the reaction obtained from the air, in elevating it. The posterior bands are stronger than the anterior ones to restrain within certain limits the strong tendency which the wing has to leap forward in curves towards the end of the down and up strokes. The oblique bands, aided by the air, give the necessary degree of rotation to the wing in the direction of its length. This effect can, however, also be produced independently by the four principal bands. From what has been stated it will be evident that the elastic bands exercise a restraining influence, and that they act in unison with the driving power and with the reaction supplied by the air. They powerfully contribute to the continuous vibration of the wing, the vibration being peculiar in this that it varies in rapidity at every successive stage. I derive the motor power, as has been stated, from a direct piston action, the piston being urged either by steam worked expansively or by the hand, if it is merely a question of illustration. In the hand models the "*muscular sense*" at once informs the operator as to what is being done. Thus if one of the wave wings supplied with a ball and socket joint, and a cross system of elastic bands as explained, has a sudden vertical impulse communicated to it at the beginning of the down stroke, the wing darts *downwards and forwards in a curve* (*vide a, c,* of fig. 14, page 344), and in doing so *it elevates* and carries the piston and cylinder *forwards.* The force employed in depressing the wing is partly expended in stretching the superior elastic band (*y* of fig. 63, page 424), the wing being slowed towards the end of the down stroke. The instant the depressing force ceases to act the superior elastic band (*y*) contracts, and the air reacts; the two together, coupled with the tendency which the model has to fall downwards and forwards during the up stroke, elevating the wing. The wing when it ascends describes an *upward and forward curve,* as shown at *c e* of fig. 14, page 344. The ascent of the wing stretches the inferior elastic band (*z* of fig. 63, page 424) in the same way that the descent of the wing stretched the superior band. The superior and inferior elastic bands antagonise each other and reciprocate with vivacity. While those changes are occurring the wing is *twisting* and *untwisting* in the direction of its length and developing figure of eight curves along its margins (page 423, fig. 62, *a b, c d*), and throughout its substance similar to what are observed under like circumstances in the natural wing (*vide* figs. 39, 40, 41, 42, and 43, page 362). The angles, moreover, made by the under surface of the wing with the horizon during the down and up strokes are continually varying—the wing all the while acting as a kite, which flies steadily *upwards and forwards* (fig. 15, page 345). As the elastic bands, as has been partly explained, are antagonistic in their action the wing is constantly oscillating

in some direction, there being no dead point either at the end of the down or up strokes. As a consequence, the curves made by the wing during the down and up strokes respectively, run into each other to form a continuous waved track, as represented at figs. 13, 14, and 15, pages 342, 344, and 345. A continuous movement begets a continuous buoyancy, and it is quite remarkable to what an extent, wings constructed and applied to the air on the principles explained, elevate and propel—how little power is required, and how little of that power is wasted in slip.

If the piston, which in the experiment described has been working *vertically*, be made to work *horizontally*, a series of essentially similar results are obtained. When the piston is worked horizontally, the anterior and posterior elastic bands require to be of nearly the same strength, whereas the inferior elastic band requires to be much stronger than the superior one, to counteract the very decided tendency the wing has to fly upwards. The power also requires to be somewhat differently applied. Thus the wing must have a violent impulse communicated to it when it begins the stroke from right to left, and also when it begins the stroke from left to right (the *heavy parts* of the spiral line represented at fig. 8, page 340, indicate the points where the impulse is communicated). The wing is then left to itself, the elastic bands and the reaction of the air doing the remainder of the work. When the wing is forced by the piston from right to left, it darts forwards in a double curve, as shown at fig. 70, the various inclined surfaces made by the wing with the horizon changing at every stage of the stroke.

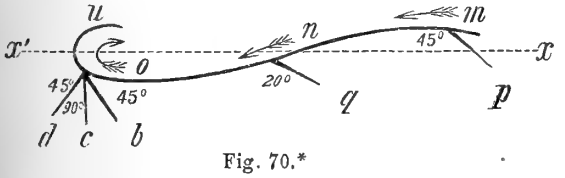


Fig. 70.*

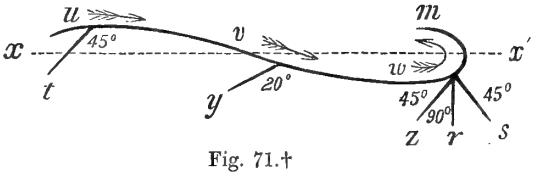


Fig. 71.†

At the beginning of the stroke from right to left, the angle made by the under surface of the wing with the horizon ($x\ x'$) is something like 45°, whereas at the middle of the stroke it is reduced to 20° or 25°. At the end of the stroke the angle gradually increases to 45°, then to 90°, after which the wing suddenly turns a somersault, and reverses precisely as the natural wing does at e, f, g of figs. 3 and 5, page 338. The artificial wing reverses with amazing facility, and in the most natural manner possible. The angles made by its under surface

* Fig. 70. Stroke of artificial wave wing from right to left. x, x', Horizon. m, n, o, Wave track described by wing from right to left. p, Angle made by wing at beginning of stroke. q, Ditto, made at middle of stroke. b, Ditto, towards end of stroke. c, Wing in the act of reversing; at this stage the wing makes an angle of 90° with the horizon, and its speed is less than at any other part of its course. d, Wing reversed, and in the act of darting up to u, to begin the stroke from left to right (*vide* u of fig. 71).

† Fig. 71. Stroke of artificial wave wing from left to right. x, x', Horizon. u, v, w, Wave track described by wing from left to right. t, Angle made by the wing with the horizon at beginning of stroke. y, Ditto, at middle of stroke. z, Ditto, towards end of stroke. r, Wing in the act of reversing; at this stage the wing makes an angle of 90° with the horizon, and its speed is less than at any other part of its course. s, Wing reversed, and in the act of darting up to m, to begin the stroke from right to left (*vide* m of fig. 70).

with the horizon, depend chiefly upon the speed with which the wing is urged at different stages of the stroke, the angle always decreasing as the speed increases, and *vice versa*. As a consequence, the angle is greatest when the speed is least.

The course described, and the angles made by the artificial wave wing with the horizon during the stroke from right to left, are represented at fig. 70, page 435.

When the wing reaches the point *b*, its speed is much less than it was at *q*. The wing is, in fact, preparing to reverse. At *c* the wing is in the act of reversing (compare with *c* of figs. 16 and 17, page 349), and, as a consequence, its speed is at its minimum, and the angle which it makes with the horizon at its maximum. At *d* the wing is reversed, its speed being increased, and the angle which it makes with the horizon diminished. Between the letters *d* and *u* the wing darts suddenly up like a kite, and at *u* it is in a position to commence the stroke from left to right, as indicated at *u* of fig. 71 p. 435. The course described, and the angles made by the wing with the horizon during the stroke from left to right, are represented at fig. 71 (compare with figs. 4 and 6, page 338). The stroke from left to right is in every respect the converse of the stroke from right to left, so that a separate description is unnecessary.

The Artificial Wave Wing can be driven at any speed—it can make its own currents, or utilise existing ones.—The remarkable feature in the artificial wave wing is its adaptability. It can be driven slowly, or with astonishing rapidity. It has no dead points. It reverses instantly, and in such a manner as to dissipate neither time nor power. It alternately seizes and evades the air so as to extract a maximum amount of support with a minimum of slip, and with a minimum expenditure of power. It supplies a degree of buoying and propelling power which is truly remarkable. Its buoying area is nearly equal to half a circle. It can act upon still air, and it can create and utilise its own currents. I proved this in the following manner. I caused the wing to make a horizontal sweep from right to left over a candle; the wing rose steadily as a kite would, and after a brief interval, the flame of the candle was persistently blown from right to left. I then waited until the flame of the candle assumed its normal perpendicular position, after which I caused the wing to make another and opposite sweep from left to right. The wing again rose kite fashion, and the flame was a second time affected, being blown in this case from left to right. I now caused the wing to vibrate steadily and rapidly above the candle, with this curious result, that the flame did not incline alternately from right to left and from left to right. On the contrary, it was blown steadily away from me, *i.e.*, in the direction of the tip of the wing, thus showing that the artificial currents produced, met and neutralised each other always at mid stroke. I also found that under these circumstances the buoying power of the wing was remarkably increased.

Compound rotation of the Artificial Wave Wing: the different parts of the Wing travel at different speeds.—The artificial wave wing, like the natural wing, revolves upon two centres (*a b, c d* of fig. 45, page 376, and *x, l* of fig. 63, page 424), and owes much of its elevating and propelling, seizing and disentangling power to its different portions travelling at different rates of speed (see fig. 51, page 399), and to its storing up and giving off energy as it hastens to and fro. Thus the tip of the wing moves through a very much greater space in a given time than the root, and so also of the posterior margin as compared with the anterior. This is readily understood, by bearing in mind that the root of the wing forms the centre or axis of rotation for the tip; while the anterior margin is the centre or axis of rotation for the posterior margin. The momentum, moreover, acquired by the wing during the stroke from right to left *is expended in reversing the wing*, and in preparing it for the stroke from left to right, and *vice versa;* a continuous to and fro movement devoid of dead points being thus established. If the artificial wave wing be taken in the hand and suddenly depressed *in a more or less vertical direction*, it immediately springs up again, and carries the hand with it. It, in fact, describes a curve whose convexity is directed downwards, and in doing so, carries the hand upwards and forwards. If a second down stroke be added, a second curve is formed; the curves running into each other, and producing a progressive waved track similar to what is represented at *a, c, e, j, i* of fig. 14, page 344. This result is favoured if the operator runs forward so as not to impede or limit the action of the wing.

How the Wave Wing creates currents, and rises upon them, and how the air assists in elevating the Wing.—In order to ascertain in what way the air contributes to the elevation of the wing, I made a series of experiments with natural and artificial wings. On concluding these experiments, I felt convinced that when the wing descends it compresses and pushes before it, in a downward and forward direction, a column of air represented by *a, b, c* of fig. 72, p. 438.* The air rushes in from all sides to replace the displaced air, as shown at *d, e, f, g, h, i*, and so produces a circle of motion indicated by the dotted line *s, t, v, w*. The wing rises upon the outside of the circle referred to, as more particularly seen at *d, e, v, w*. The arrows, it will be observed, are all pointing upwards, and as these arrows indicate the direction of the reflex or back current, it is not difficult to comprehend how the air comes indirectly to assist in elevating the wing. A similar current is produced to the right of the figure, as indicated by *l, m, o, p, q, r*, but seeing the wing is always advancing, this need not be taken into account.

* The artificial currents produced by the wing during its descent may be readily seen by partially filling a chamber with steam, smoke, or some impalpable white powder, and causing the wing to descend in its midst. By a little practice, the eye will not fail to detect the currents represented at *d, e, f, g, h, i, l, m, n, o, p, q, r* of fig. 72, p. 438.

If fig. 72 be made to assume a horizontal position, instead of the oblique position which it at present occupies, the manner in which *an artificial current* is produced by one sweep of the wing from right to left, and utilised by it in a subsequent sweep from left to right, will be readily understood. The artificial wave wing makes a horizontal sweep from right to left, *i.e.*, it passes from the point *a* to the point *c* of fig. 72. During its passage it has displaced a column of air. To fill the void so created, the air rushes in from all sides, viz., from *d, e, f, g, h, i; l, m, o, p, q, r.* The currents marked *g, h, i; p, q, r,* represent the reflex or *artificial currents.* These are the currents which, after a brief interval, force the flame of the candle from right to left. It is those same currents which encounter the wing, and contribute so powerfully to its

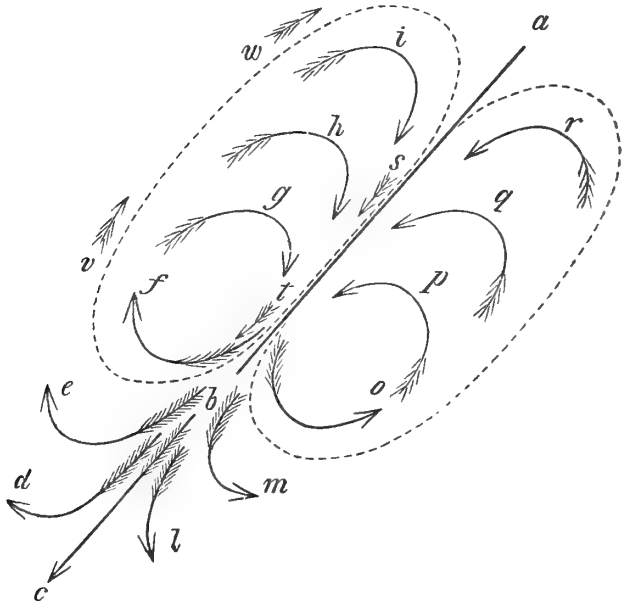


Fig. 72.

elevation, when it sweeps from left to right. The wing, when it rushes from left to right, produces a new series of artificial currents, which are equally powerful in elevating the wing when it passes a second time from right to left, and thus the process of making and utilising currents goes on so long as the wing is made to oscillate. In waving the artificial wing to and fro, I found the best results were obtained when the range of the wing and the speed with which it was urged were so regulated as to produce a perfect reciprocation. Thus, if the range of the wing be great, the speed should also be high, otherwise the air set in motion by the right stroke will not be utilised by the left stroke, and *vice versa.* If, on the other hand, the range of the wing be small, the speed should also be low, as the short stroke will enable the wing to reciprocate as perfectly as when the stroke is longer and the

speed quicker. When the speed attained is high, the angles made by the under surface of the wing with the horizon are diminished; when it is low, the angles are increased. From these remarks it will be evident that the artificial wave wing reciprocates in the same way that the natural wing reciprocates, the reciprocation being most perfect when the wing is vibrating in a given spot, and least perfect when it is travelling at a high horizontal speed.

The Artificial Wing propelled at various degrees of speed during the down and up strokes.—The tendency which the artificial wave wing has to rise again when suddenly and vigorously depressed, explains why the *elevator* muscles of the wing should be so small when compared with the *depressor* muscles—the latter being something like seven times larger than the former. That the contraction of the elevator muscles is necessary to the elevation of the wing, is abundantly proved by their presence, and that there should be so great a difference between the volume of the elevator and depressor muscles is not to be wondered at, when we remember that the whole weight of the body is to be elevated by the rapid descent of the wings—the descent in question being entirely due to the vigorous contraction of the pectoralis major. If, however, the wing was elevated with as great a force as it is depressed, it is plain that the good effected during the descent would be utterly undone, as the wing, during its ascent, would experience a much greater resistance from the air than it did during its descent. The wing is consequently elevated more slowly than it is depressed, the elevator muscles exercising a controlling and restraining influence. By slowing the wing during the up stroke, the air has an opportunity of reacting on its under surface, as explained at page 351.

The Artificial Wave Wing as a Propeller.—The wave wing makes an admirable propeller if its tip be directed *vertically downwards*, and the wing lashed from side to side with a sculling figure of 8 motion, similar to that executed by the tail of the fish. Three wave wings may be made to act in concert and with a very good result; two of them being made to vibrate figure of 8 fashion in a more or less horizontal direction with a view to elevating, the third being turned in a downward direction, and made to act vertically for the purpose of propelling.

A New Form of Aerial Screw.—If two of the wave wings represented at fig. 62, page 423, be placed end to end, and united to a vertical portion of tube to form a two-bladed screw, similar to that employed in navigation, a most powerful elastic aerial screw is at once produced, as seen at fig. 73, page 440.

This screw, which for the sake of uniformity I denominate *the aerial wave screw*, possesses advantages for aerial purposes to which no form of *rigid* screw yet devised can lay claim. The way in which it clings to the air during its revolution, and the degree of buoying power it possesses are quite astonishing. It is a self-adjusting, self-regulating screw, and as its component parts are

flexible and elastic, it accommodates itself to the speed at which it is driven, and gives a uniform buoyancy. The slip I may add is nominal in amount. This screw is exceedingly light, and owes its efficacy to its shape and the graduated nature of its blades, the anterior margin of each blade being comparatively rigid, the posterior margin being comparatively flexible and more or less elastic. The blades are kites in the same sense that natural wings are kites, and are flown as such when the screw revolves. I find the aerial wave screw flies best and elevates most when its blades are inclined at a certain upward angle as indicated in the figure (73). The aerial wave screw may have the numbers of its blades increased by placing the one above the other, and two or more screws may be combined and made to revolve in opposite directions so as to make them reciprocate, the one screw producing the current on which the other rises, as happens in natural wings.

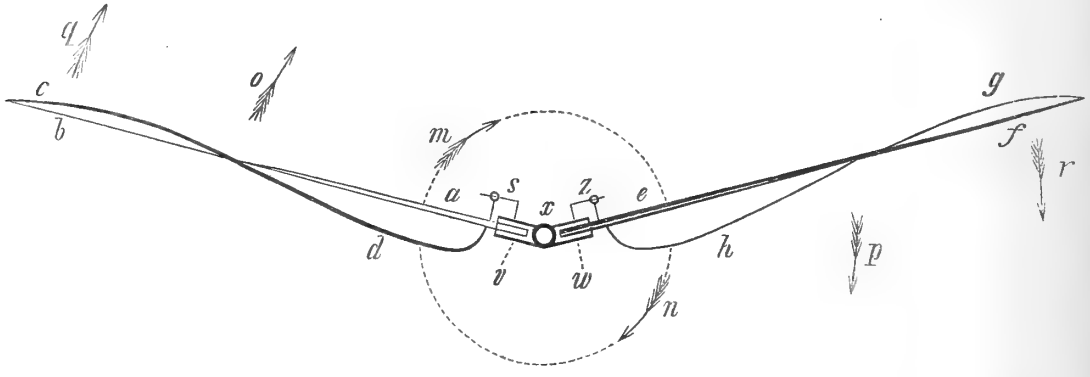


Fig. 73.*

The Aerial Wave Screw operates also upon Water.—The form of screw just described is adapted in a marked manner for water, if the blades be made of carefully tempered finely graduated steel plates and reduced in size. It bears the same relation to, and produces the same results upon, water as the tail and fin of the fish. It throws its blades during its action into double figure of 8 curves, similar in all respects to those produced on the anterior and posterior margins of the natural and artificial flying wing. As the speed attained by the several portions of each blade varies, so the angle at which each part of the

* Fig. 72. Aerial wave screw whose blades are slightly twisted upon themselves (*a b*, *c d*; *e f*, *g h*), so that those portions nearest the root (*d h*) make a greater angle with the horizon than those parts nearer the tip (*b f*). The angle is thus adjusted to the speed attained by the different portions of the screw. The angle admits of further adjustment by means of the steel springs *z*, *s*, these exercising a restraining, and to a certain extent a regulating influence which effectually prevents shock.

It will be at once perceived from this figure that the portions of the screw marked *m* and *n* travel at a much lower speed than those portions marked *o* and *p*, and these again more slowly than those marked *q* and *r*. As however the angle which a wing or a portion of a wing, as I have pointed out, varies to accommodate itself to the speed attained by the wing, or a portion thereof, it follows, that to make the wave screw mechanically perfect, the angles made by its several portions must be accurately adapted to the travel of its several parts as indicated above.

x, Vertical tube for receiving driving shaft. *v*, *w*, Sockets in which the roots of the blades of the screw rotate, the degree of rotation being limited by steel springs *z*, *s*. *a b*, *e f*, Tapering elastic reeds forming anterior or thick margins of blades of screw. *d c*, *h g*, Posterior or thin elastic margins of blades of screw. *m n*, *o p*, *q r*, Radii formed by the different portions of the blades of the screw when in operation. The arrows indicate the direction of travel.

blade strikes varies, the angles being always greatest towards the root of the blade and least towards the tip. The angles made by the different portions of the blade are diminished in proportion as the speed with which the screw is driven is increased. The screw in this manner is self-adjusting, and extracts a large percentage of propelling power with very little force and surprisingly little slip.

A similar result is obtained, if two finely graduated angular-shaped steel plates be placed end to end and applied to the water (vertically or horizontally matters little), with a slight sculling figure of 8 motion, analogous to that performed by the tail of the fish, porpoise, or whale. If the thick margin of the plates be directed forwards, and the thin ones backwards, an unusually effective propellor is produced. This form of propellor is likewise very effective in air.

EXPLANATION OF THE PLATES.

Plate XI.

Figures 1, 2, and 3 show how the wing of the gull is elevated and extended towards the termination of the up stroke to prepare it for making the down stroke. At figure 3 the wing is represented as folded upon itself, and in the act of being elevated. It is, therefore, elevated as a *short lever*, the resistance experienced from the superimposed air being thus greatly diminished. The wing acts as a short lever from the time it leaves the position indicated by 6 of figure 6 until it assumes the position indicated by *o* of figure 3. At figure 2 the wing is raised higher than in figure 3, and partly extended—the elevation and extension of the wing occurring simultaneously. At figure 1 the wing is fully elevated and fully extended, and, consequently, ready to make the down stroke. It descends as a *long lever*, with great energy, until it assumes the position indicated by 4 of figure 6. The resistance which the wing experiences from the air beneath, is consequently, very great, the buoying power of the wing bearing a fixed relation to the resistance in question. The under surface of the wing, when in the position represented at figure 3, makes a very slight angle with the horizon *b d*. This arises from the fact that the different portions of the wing, when the wing is folded upon itself, are on nearly the same plane. The angle or angles —for they are numerous—made by the under surface of the wing with the horizon become larger when the wing is partly extended, as shown at figure 2 : *b d*, representing the horizon, and *c b d* the angle which the root of the wing makes with it. The angles become still larger when the wing is fully extended, as a comparison of *c b d* of figure 1 with *c b d* of figure 2 will show. The under surface of the wing, it will be observed, makes a variety of inclined surfaces with the horizon while the pinion is being extended. The angles of inclination made by the inclined surfaces in question are increased and diminished by the ascent or descent of the posterior margin of the wing, *o p q* (the anterior margin acts as an axis to the posterior one), the angles being always greatest when the wing is extended, and least when it is flexed. The angles, moreover, made by the root of the wing are always greater than those made by the tip. The various inclined surfaces made by the under surface of the wing are intimately associated with the power the wing possesses of alternately seizing and evading the air. The angles are greater at the root of the wing than at the tip, because the portions of the pinion nearer the root travel at a lower speed than portions nearer the tip. The various inclined surfaces made by the wing in flexion and extension are well seen at figures 16 and 17, Plate XIII. At figure 17 the anterior margin of the wing (*x s t v w*) is nearly on a level with the posterior margin (*o, p, q*). At figure 16, on the other hand, the anterior margin (*x, s, t, v, w*) is elevated and the posterior margin (*o p q*) depressed. A careful examination of those figures (particularly figure 16) will also show that the angles of inclination made by the several portions of the under surface

of the wing vary—the angle made by the part *q* of figure 16 with the horizon being greater than that made by the part *p*—this, again, being greater than that made by the tip of the wing *o*. Those points are also illustrated at figure 8, Plate XII. The letters in figures 1, 2, and 3 (Plate XI.) represent the same parts of the wing—*x*, shoulder joint; *s*, elbow joint; *t*, wrist joint; *v*, *w*, hand and finger joints; *x s t v w*, anterior margin of wing; *o p q*, posterior margin.

Figure 4 represents the very oblique and almost horizontal direction of the stroke of the wing in the flight of the insect (wasp)—how the wing is twisted upon itself at the end of the up (*a*) and down (*b*) strokes, and how the tip of the wing, during its vibration, describes a figure of 8 track in space (*a, c, b*).

Figures 5 and 6 show the more or less perpendicular direction of the stroke of the wing in the flight of the bird (gull)—how the wing is gradually extended as it is elevated (1, 2, 3 of figure 5)—how it descends as a long lever until it assumes the position indicated by 4 of figure 6—how it is flexed towards the termination of the down stroke, as shown at 4, 5, 6 of figure 6, to convert it into a short lever (*a b*), and prepare it for making the up stroke. The difference in the length of the wing during flexion and extension is indicated by the short and long levers *a b* and *c d* of figure 6. The sudden conversion of the wing from a long into a short lever at the end of the down stroke is of great importance, as it robs the wing of its momentum, and prepares it for reversing its movements. Those same points are illustrated at figures 18 and 19, Plate XIV. At 4 of figure 19 the wing is represented as fully extended, and in the middle of the down stroke. At 5 of the same figure the wing is being flexed and slowed, and at 6 it is fully flexed, and its momentum destroyed. The wing is then elevated as a short lever until it assumes the position indicated at 1′ of figure 18. It is subsequently elevated and extended, as shown at 2′ and 3′ (fig. 18). At 3′ it is transformed into a long lever, and in a condition to make a second down stroke. Figure 19 also shows the compound rotation of the wing—the tip of the wing rotating upon the axis *c d*, and describing an arc of a circle, *e f*—the posterior margin of the wing rotating upon the axis (*a b*), and describing the arc *g h*. The compound rotation of the wing occurs simultaneously with the down and up strokes, and it is to it that the great variety of inclined surfaces made by the under surface of the wing is principally due.

Plate XII.

Figure 7 is designed to show that the angle made by the under surface of the wing (more particularly at its root) with the horizon, is much greater than is generally supposed. This arises from the fact that the body of the bird is inclined in an upward direction in flight, and because the anterior margin of the wing (*a*) curves in a downward direction in such a manner as to conceal the actual angle made. Thus, if *e f* be taken to represent the horizon, the angle apparently made by the under surface of the wing with it is *a b d*. The real angle, however, is *c b d*.

Figure 8. The lapwing, or green plover (*Vanellus cristatus*, Meyer), with one wing fully extended (*c b*, *d′ e′ f′*), the other being in a semiflexed condition (*d e f*, *c b*). In the extended wing the anterior or thick margin (*d′ e′ f′*) of the pinion is directed *upwards and forwards* (*vide* arrow), the posterior or thin margin (*c b*) downwards and backwards. The reverse of this happens during flexion, the anterior or thick margin (*d e f*) of the pinion being directed slightly *downwards and forwards* (*vide* arrow), the posterior or thin margin bearing the rowing feathers slightly *upwards and backwards*. The wings, therefore, twist in opposite directions during extension and flexion. In the flexed condition of the wing the anterior (*d e f*) and posterior (*b c*) margins are nearly on the same level, and the wing acts as a short lever. In this condition of the pinion the primary or rowing feathers (*b*) are separated from each other, and inclined obliquely upwards and outwards. (These feathers are also shown at 1, 2, 3, 4, 5, 6, 7, 8, 0, 9 of figure 46, page 378.) When, therefore, the wing ascends, the feathers in question (as well as the secondary feathers) cut into the air like so many knives. They thus diminish the resistance experienced from the superimposed air during the up stroke, a result to which the flexing or folding of the wing and its conversion into a short lever contributes. From this account it will be seen that when the wing is flexed the angles made by its under surface with the horizon are diminished, whereas those made by the individual primary and secondary feathers are increased. When the wing is extended it rotates in the direction of its length, the anterior margin (*d e f*) being gradually inclined upwards and backwards, the posterior

one downwards and forwards. The rotation of the wing on its long axis during extension increases the angles made by the under surface of the wing with the horizon, but decreases the angles made by the individual primary and secondary feathers, these being made to flap together, and to assume a more or less horizontal position, as is well shown at *a b c d e f g h i j k l m n o p q* of figure 48, page 378. This flapping together of the primary and secondary feathers during extension effectually prevents the air from passing between them. The power of the wing is greatly augmented during the down stroke—1st, by its being converted into a long lever; 2d, by the flapping of the feathers together; 3d, by its under surface being rendered deeply concave (page 378, figure 48); and 4th, by the various angles of inclination made by the several portions of the under surface of the wing with the horizon being increased. These points are further illustrated at figures 16 and 17, Plate XIII. At figure 17 the margins of the primary (*o p*) and secondary (*q*) feathers, as seen in flexion, are given; whereas in figure 16 the flat of the feathers (*o p q*), as seen in extension, are shown. These figures also show that, as the angles made by the under surface of the wing with the horizon increase, the angles made by the individual primary and secondary feathers (*o p q*) decrease, and *vice versa*. The angles made by the primary and secondary feathers are increased during the up stroke, when the speed of the wing is slowed, and decreased during the down stroke, when the speed is increased, an inclined surface, which forms a large angle with the horizon, giving, when forced against the air at a low speed, the same amount of buoying power as an inclined surface, which forms a smaller angle when urged at a lower speed.

Figures 9, 10, and 11 (Plate XII.) show the wing of the gannet in the flexed, semiflexed, and extended condition. Those figures are also intended to illustrate how the various inclined surfaces made by different portions of the under surface of the wing in extension and flexion are directed forwards, backwards, outwards, and inwards. Thus in flexion and semiflexion (figures 9 and 10), the portions of the wing marked *g h* and *c d*, are inclined upwards and inwards (*vide* arrows), whereas the portions marked *e f* and *a b* are inclined upwards and outwards. When the wing is being extended, as in figure 10, the portions marked *e f* and *a b* produce or draw after them a current, on which the portions marked *c d* and *g h* operate when the wing is being flexed, and *vice versa*. When the wing is fully extended, as at figure 11, the inclined surfaces indicated by *g h*, *c d*, *e f*, and *a b* of figures 9 and 10 disappear, the under surface of the wing making a variety of inclined surfaces, which are directed principally upwards and forwards, as shown at figure 16, Plate XIII. It is in this way that the wing is capable of change of form in all its parts, and it will be observed that those changes are induced irrespectively of any resistance experienced from the air. When the wing ascends, it draws after it a current on which it operates when it descends; and when the wing descends, it produces a current which assists in the elevation of the wing. By the acts of flexion and extension, and by the down and up strokes, the wing of the bird and bat produces the whirlwind on which it depends for support and progress. The tip of the wing rotates upon *t* of figures 9 and 10 (Plate XII.) as a centre, and by its alternately darting in and out in flexion and extension, it describes the segment of a circle (*m n*), and contributes to the stability of the bird by increasing the area of support.

The letter *x* in figures 9, 10, and 11 indicates the shoulder joint; *s*, the elbow joint; *t*, the wrist joint; *v* and *w*, the hand and finger joints; *o p* (fig. 11), the primary feathers; *p q*, the secondary feathers; *r* the tertiary feathers; *x s t v w*, the anterior margin of the wing; and *o p q r* the posterior margin.

Figure 12 shows how the wing is twisted upon itself structurally, and how the tip of the wing forms an inclined surface, which is directed upwards and outwards (see arrows marked *a* and *b*). *x*, *m*, *n*, anterior margin of wing; *o p q*, posterior margin.

Plate XIII.

Figures 13, 14, and 15 represent the flight of the gull with the wings in the flexed, semi-flexed, and extended conditions. The letters indicate the same parts of the wing in all the figures, *x* representing the shoulder joint, *s* the elbow joint, *t* the wrist joint, and *v* and *w* the hand and finger joints; *o p* the primary feathers, and *q* the secondary ones. At figure 15 the wings are fairly twisted upon themselves, and form true screws. In this figure the pinions are extended to their utmost, and affording their maximum of support. They are represented as they are seen at the middle of the down stroke. At figure 14 the

wings are slightly flexed and deeply concave on their under surfaces, the greater concavity of the wings compensating in part for the diminution in their length. They are also further depressed than in figure 15. At figure 13 the wings are represented as seen at the end of the down stroke, the concavity of their under surfaces being still more increased, and their length still more diminished. The wings are now short levers, and prepared to make the up stroke, the great convexity of their upper surfaces diminishing the resistance which they experience from the superimposed air during their ascent. Figures 13, 14, and 15 illustrate very clearly how the downward and forward fall of the body during the up stroke contributes to the elevation of the wings. Thus in figure 13 the body is up and the wings down. At figure 14 the body has fallen a little, and the wings are elevated and spread out more than in fig. 13. At figure 15 the body has fallen further, and the wings are spread out to their utmost, and on a level with the body. If we now turn to figure 18 of Plate XIV. we will see that the body continues to fall and the wings to rise, as shown at 1, 2, 3; 1′ 2′ 3′. At 3, 3′ of this figure the wings are elevated to their utmost, and the body depressed to its utmost. The wings are consequently in a position to make a new down stroke. From these figures it will be evident that the wings and body rise and fall alternately, the fall of the body contributing to the elevation of the wings, and the descent of the wings necessitating the ascent of the body. It is in this way that the weight of the body comes to play an important part in flight. The alternate waved tracks described by the wings and body in flight are given at figure 14, page 344; *a*, *c*, *e*, *g*, *i* giving the undulations made by the wings; 1, 2, 3, 4, 5, those made by the body.

Figures 16 and 17 (Plate XIII.) show the wing in the extended and flexed condition in the gannet. In these figures the body of the bird is exactly in the same position. When the wing is flexed, as in figure 17, it is crushed together, the tip of the wing (*s*, *p*, *v*, *w*) folding beneath the central portion (*p*, *q*, *t*), the central portion and root (*x s r*) flapping together on nearly the same plane. It is by this means that the wing is converted from a long into a short lever. The flexing of the wing reduces the angles of inclination formed by the several portions of the under surface of the wing with the horizon, and causes the anterior (*x*, *s*, *t*, *v*, *w*) and posterior (*o p q*) margins of the pinion to occupy nearly the same level. It, however, increases the angles of inclination made by the primary and secondary feathers, these changes being necessary to reduce the resistance experienced from the air during the up stroke. When the wing is flexed, all its parts are in a lax condition, the wing being principally under the control of the elastic ligaments, the muscles acting more especially during extension. When the wing is pushed away from the side of the body, and extended as represented at figure 16, the angles of inclination made by the several portions of the under surface of the pinion with the horizon are increased, while those made by the primary (*o p*) and secondary (*p q*) feathers are diminished. The pinion, moreover, is rendered more or less rigid. When the wing is fully extended, it acts as a long lever (compare length of wing in figures 16 and 17). By increasing its length, the wing also increases its power and speed towards the tip. It therefore attacks the air with great violence during the down stroke, and insures a corresponding upward recoil of the body. The angles of inclination made by the several portions of the under surface of the wing with the horizon vary. Thus the angle made by the portion *q s* is greater than that made by the portion *p v*, and that made by *p v* greater than that made by *o w*. The diminution and increase of the angles bears a fixed relation to the speed at which the different portions of the wing travel, the angle always being greatest when the speed is lowest, and *vice versa*. The change in the angles is principally due to the rotation of the wing in the direction of its length, the posterior margin of the pinion rotating round the anterior one in a *downward direction* during extension (figure 16, *vide* arrows), and in an *upward direction* during flexion (figure 17, *vide* arrows). It is this rotation of the wing upon its long axis which presents the upper or dorsal surface of the pinion to the spectator in flexion (figure 17), and the under or ventral surface in extension (figure 16.) These points are further illustrated at figure 8, Plate XII. (see description of figure 8.) In figures 16 and 17 the same letters are affixed to the same portions of the wing in both; *x* representing the shoulder joints; *s*, the elbow joint; *t* the wrist joint; *v*, *w*, the hand and finger joints; *o p*, the primary feathers; *p*, *q*, the secondary feathers; *r*, the tertiary feathers; *x*, *s*, *t*, *v*, *w*, the anterior margin of the pinion; *o p q*, the posterior margin.

Plate XIV.

Figures 18 and 19 represent the several positions assumed by the wing of the gull during extension and flexion, and during the down and up strokes. Figure 19 also shows how the wing during its ascent and descent rotates upon two axes. At 4 of figure 19 the wings are represented as they appear at the middle of the down stroke. They are fully extended, and affording their maximum of support. At 5 of this figure the wings are slightly flexed, and more deeply arched than at 4. They are also on a lower level. At 6 the wings are represented as they appear at the end of the down stroke. They are now fully flexed and form short levers. They are also more deeply arched than at 5, a circumstance which prepares them for making the up stroke, as the arching renders the upper or dorsal surfaces of the wings very markedly convex. The wings, when in the positions indicated by 6 of figure 19, are elevated as short levers, until they assume the positions indicated by 1, 1′ of figure 18. The wings are then pushed away from the body, and extended and elevated, as shown at 2, 2′ and 3, 3′ (fig 18). At 3 3′ the wings are fully extended and fully elevated, and ready to make the down stroke. They descend as long levers, until they assume the positions indicated by 4 of figure 19, the changes in position just described being repeated in rapid succession as the wings vibrate. The wings are flexed towards the termination of the down stroke (5 and 6 of figure 19) to convert them into short levers, to destroy the momentum acquired by them during their descent, and to prepare them for making the up stroke. They are extended towards the termination of the up stroke (2, 2′; 3, 3′ of figure 18) to convert them into long levers, and to prepare them for making the down stroke. Figure 18 represents the bird when it is flying vigorously, or when it is rising or picking up garbage from the surface of the sea. In leisurely flight the wings do not rise much above the level of the body, as shown at figure 19. In this case the wings are made to play rather under than above the body (*vide* p. 374). The compound rotation of the wing is shown at figure 19, the wing rotating at its root (*a*) and along its anterior margin (*c b*), the tip of the wing describing the arc of one circle (*e b f*), and the posterior margin of the wing the arc of another circle (*g d h*). The compound rotation of the wing is further illustrated at figure 45, page 376.

Figure 20. Wing of the piet in the extended position.—In this figure the under lapping of the primary (1 2 3 4 5 6 7 8 9) and secondary (*j k l m n o p q r s*) feathers are shown, and how the axis of each primary feather occupies a more and more central position in proportion as it is placed nearer the secondary feathers. This want of symmetry in the primary feathers is necessary to their valvular action during flexion and extension. The wing during its vibration forces a certain portion of the air in waves along its under surface in the direction of its root, as indicated by the arrows and dotted lines; the greater portion of the air, however, is urged from the tip and posterior margin of the wing in a backward and downward direction, the reaction propelling the body upwards and forwards. The commotion produced in the air by the tip and posterior margin of the wing is on all occasions very great, as the exposure of a flame behind or to the outside of the wing will readily satisfy.

Plate XV.

Figures 21 and 22 represent the muscles and elastic ligaments of the wings of the snipe, as seen on the ventral and dorsal aspects. In figure 21 (ventral aspect) the wing to the right of the observer is fully extended, and the elastic ligaments put upon the stretch. The wing to the left of the observer is represented as flexed, the elastic ligaments being in a state of contraction. The same points are illustrated at figure 22, which represents the dorsal aspect of the bird. The wing is flexed principally by the action of the elastic ligaments. It is extended chiefly by voluntary muscular efforts. Those figures show the difference in the length of the wing in the extended and flexed condition, the pinion being a long lever in extension, and a short one in flexion. That the elastic ligaments are subsidiary, and to a certain extent under the control of the muscular system, is evident from the fact that voluntary muscular fibres run into the ligaments in question. Thus the voluntary muscular slip marked *a* in figure 21 terminates in the fibro-elastic band *k*; this, again, being geared to voluntary muscle *x*, and to certain musculo-fibrous bands *j*. Their conjoined action is to flex the forearm upon the arm, the arm being drawn towards the body by a musculo-

fibrous ligament *d*, *e*. The elastic ligament *g*, *i* flexes the hand upon the forearm, and the ligament *r* the fingers upon the hand.

Figure 23 shows the muscles and elastic ligaments in the wings of the pheasant, as seen on the dorsal aspect, the wing to the right of the observer being fully extended, that to his left being fully flexed. In the former the elastic ligaments are put upon the stretch; in the latter, they are in a state of contraction.

a, *b*, Voluntary muscular fibres, terminating in fibrous and elastic tissues *c* and *k*. These structures act in conjunction, and fold or flex the forearm on the arm.

f h, Voluntary muscular fibres, sending processes into elastic ligament *g i*, to flex the hand upon the forearm. The arm is drawn towards the body by the elastic ligament *d*, and by the muscles *v*, *w*.

Plate XVI.

Figures 24 and 28 show the muscles and elastic ligaments, and the arrangement of the primary and secondary feathers on the ventral and dorsal aspects of the wing of the crested crane. The wing is in the extended condition in both cases.

a b, Voluntary muscular fibres terminating in elastic band *k*. This band splits up into two portions (*k*, *m*, figure 24). A somewhat similar band is seen at *j* (figure 24). These three bands are united to, and act in conjunction with, the great fibro elastic web *c*, to flex the forearm on the arm.

f g, *h*, *i*, Musculo-fibro-elastic ligament, which envelopes the roots of the primary and secondary feathers. The musculo-fibro-elastic ligament forms a symmetrical network of great strength and beauty, its component parts being arranged in such a manner as to envelope the root of each individual feather. The network in question supports the feathers, and limits their peculiar valvular action. It is enlarged at figures 25 and 27, and consists of three longitudinal bands, *r s*, *t u*, *v w*. Between these bands two oblique bands, *g* and *h*, run; the oblique bands occurring between every two feathers. The marginal longitudinal band (*v*, *w*) splits up into two processes, one of which curves round the root of each feather (*x*) in a direction from right to left (*a*, *b*, *c*), the other in a direction from left to right (*d*, *e*, *f*). These processes are also seen at *m*, *n* of figure 26. They have the root of each feather completely under control, and their function, in conjunction with the oblique bands, is to rotate the feathers from right to left during flexion, and from left to right during extension. The longitudinal and oblique bands are so geared together that they work in harmony, all the feathers enveloped by them being made to rotate in the same direction at exactly the same instant of time. It is in virtue of the rotation of the individual primary and secondary feathers at their roots that the feathers are separated from each other during flexion, and brought into close contact during extension; and thus it is that the air is avoided during the up stroke, and seized during the down one. The primary and secondary feathers are supported on their dorsal aspects by a series of subsidiary feathers (*m n o p* of figure 28), which are placed obliquely across their roots, and act as buffers. The subsidiary feathers prevent the primary and secondary feathers from rising too far during the down stroke.

Figures 25, 26, and 27. See under figures 24 and 28.

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XVI.—*Additional Note on the Motion of a Heavy Body along the Circumference of a Circle.* By Edward Sang, Esq., F.R.S.E.

(Read 19th December 1870.)

In the twenty-fourth volume of the Society's Transactions, a very convenient formula is given for computing the time of oscillation in a circular arc; and the investigation of that formula is conducted by an appeal to the actual phenomena. It is defective in so far that it contemplates chiefly the time of oscillation over the whole arc, and does not enable us conveniently to compute the time in which a part of that arc is described.

The object of the present note is to supply that defect, and to present the whole subject in a new aspect remarkable alike for its generality and for its simplicity.

Referring to the first figure given in the paper cited, let N be the nadir and Z the zenith point of a circle placed upright; and let us suppose a heavy physical point to be projected from N along the circumference with a known initial velocity, the object of our inquiry is to ascertain the law of its motion, and to compute the time in which it describes a given arc.

If the initial velocity be due to a fall through the height NA greater than the diameter, the body will reach the zenith point Z with a velocity due to a descent through ZA, and will continue its motion along the other semicircumference, reaching N with the same velocity as at first; thus it will circulate along the whole circumference with a variable speed.

But if the initial velocity be that due to a fall through NB less than the diameter, the body launched in the direction Nβ will gradually lose speed until it come to rest at the point F on a level with B. Thereafter it will descend along FN, pass to the other side, and again return to N, repeating over and over again its oscillation.

In the original paper a connection was established between cases of continuous and reciprocating motion. This connection may be more neatly traced by the following scheme :—

Fig. 2.

Let a trigon have two sides AC, CB of definite length jointed together at C, and let the angle ACB gradually change. Beginning with AC, CB in a straight line, the angles at A and C are each zero. As CAB increases, ABC also increases, until, if CA be the shorter leg, CAB becomes

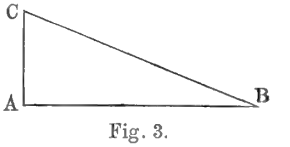

Fig. 3.

a right angle, at which instant ABC has reached a maximum value. After that, CAB still continuing to increase, ABC must decrease and become zero just when CAB becomes 180°. Afterwards, when CAB has become *reverse*, or greater than 180°, ABC appears on the other side and reaches its maximum value on that side when CAB = 270°. Thereafter ABC decreases to become zero just when CAB = 360°.

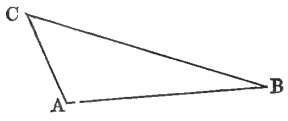

Fig. 4.

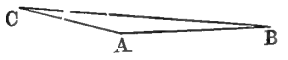

Fig. 5.

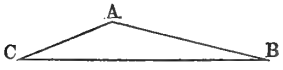

Fig. 6.

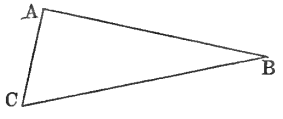

Fig. 7.

Fig. 8.

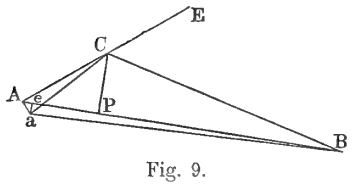

Fig. 9.

Thus the continuous growth of the angle CAB may typify the continuous motion, while the reciprocating angle ABC typifies the oscillatory motion of the heavy body. Seeing, then, that the general phases of this arrangement represent the leading characters of the two kinds of motion, we may inquire somewhat more narrowly into the resemblance. For this purpose we shall put ACB, *fig.* 9, for one form of the changeable trigon, and imagine its form to be altered by turning the arm CA into the closely approximate position C*a*, so that AC*a* becomes the decrement of the angle ACB, while AB*a* is the increment of ABC. These changes being supposed to be infinitesimally minute, the arc A*a* may be regarded as a short straight line perpendicular to CA. Draw CP and *ae* perpendicular to AB; then the minute trigon A*ea* is similar to CPA, whence $Aa : ae :: AC : AP$. Now the angle AC*a* is expressed by $\frac{Aa}{AC}$, and AB*a* by $\frac{ae}{AB}$, wherefore

$$AC\alpha : AB\alpha :: \frac{Aa}{AC} : \frac{ae}{AB} :: \frac{AC}{AC} : \frac{AP}{AB} :: AB : AP .$$

Hence, if we regard AC*a* as the differential of the exterior angle ECB, we have

$$d . ECB : d . ABC :: AB : AP , \text{ and consequently}$$
$$d . ECB : d . CAB :: AB : PB ,$$

so that the differentials of the three angles ECB, CAB, and ABC are proportional respectively to AB, BP, and PA. If then we suppose the angle at A to be generated with a velocity varying as the distance PB, that at B will be generated with a velocity proportional to AP, and the exterior angle at C with

a velocity proportional to the whole subtense AB. Putting, for shortness' sake, BC $= a$, CA $= b$, we have CP $= b \sin a$, and $PB^2 = a^2 - b^2 \sin A^2$, that is,

$$\frac{dA}{dt} \propto \sqrt{(a^2 - b^2 \sin A^2)}, \text{ and similarly}$$

$$\frac{dB}{dt} \propto \sqrt{(b^2 - a^2 \sin B^2)}.$$

When a body projected from N, with the velocity due to a descent through AN, has reached the point α, its velocity there is that which is due to a descent from A to G on the same level with α. Now, if we put Δ for the diameter NZ, H for the whole height NA, and A for the angle NZα, we have $N\alpha = \Delta . \sin A$, $NG = \Delta . \sin A^2$, $AG = H - \Delta \sin A^2$. Wherefore, if g be the intensity of gravitation as measured by the velocity which a falling body acquires in one second,

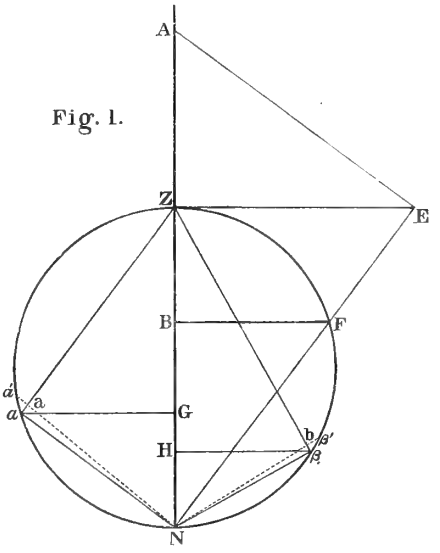

Fig. 1.

$$v_\alpha = \frac{\Delta . dA}{dt} = \sqrt{2g} . \sqrt{(H - \Delta . \sin A^2)}, \text{ or}$$

$$\frac{1}{\sqrt{(2g)}} \cdot \frac{dA}{dt} = \sqrt{\left(\frac{H}{\Delta^2} - \frac{1}{\Delta} \sin A^2\right)}.$$

Hence, if we assume in our trigon ABC,

$$\frac{dA}{dt} = PB\sqrt{2g},$$

the expression $\frac{dA}{dt} = \sqrt{2g} . \sqrt{(a^2 - b^2 \sin A^2)}$ becomes identic with

$$\frac{dA}{dt} = \sqrt{2g}\sqrt{\left(\frac{H}{\Delta^2} - \frac{1}{\Delta} \sin A^2\right)} \text{ on putting}$$

$$\frac{H}{\Delta^2} = a^2, \quad \frac{1}{\Delta} = b^2, \quad \Delta = \frac{1^3}{b^2}, \quad H = \frac{a^2}{b^4} = \Delta \frac{a^2}{b^2}.$$

In order, then, to obtain the mechanical arrangement typified by the variable trigon ABC, we must describe a circle having its diameter inversely proportional to the square of AC, and suppose the initial velocity to be that due to a descent through a height exceeding this diameter in the ratio $a^2 : b^2$. This gives us the motion represented by the variable angle A. Again, we make another circle having its diameter inversely proportional to a^2, and take a height less than this in the ratio of $b^2 : a^2$; the oscillatory motion in this arc is represented by the variations of the smaller angle B; and the time of describing

the whole circumference in the one case is equal to the time of an oscillation in the other case.

Farther, if we put C for half the exterior angle at c, that is, for the half sum of A and B, we have

$$\begin{aligned} \mathrm{AB}^2 &= a^2 + b^2 + 2ab \cos 2\mathrm{C} \\ &= a^2 + 2ab + b^2 - 4ab \sin \mathrm{C}^2 ; \end{aligned}$$

now

$$\frac{2d\mathrm{C}}{dt} = \surd 2g \,.\, \mathrm{AB} = \surd 2g \,.\, \surd\{(a+b)^2 - 4ab \sin \mathrm{C}^2\}, \text{ or}$$

$$\frac{dc}{dt} = \surd 2g \surd\left\{\left(\frac{a+b}{2}\right)^2 - ab \sin \mathrm{C}^2\right\},$$

wherefore if we put C for the half sum of a and b, d for the mean proportional between them, we have $\frac{d\mathrm{C}}{dt} = \surd 2g \,.\, \surd(c^2 - d^2 \sin \mathrm{C}^2)$, an equation identic in form with that for the variation of A. Hence if we produce AC, draw CD, *fig.* 10, bisecting the angle BCE, lay off CE a mean proportional between AC and CB, and then inflect CD equal to the half sum of these same, the distance QD, which is just half of AB, will represent the velocity with which the angle ECD changes. At the same time CQ will represent the rate of change of the angle at D, or

$$\frac{d\mathrm{D}}{dt} = \surd 2g \,\surd(d^2 - c^2 \sin \mathrm{D}^2),$$

and thus we can obtain another pair of motions, one continuous, the other alternate, synchronous with each other and with the preceding pair.

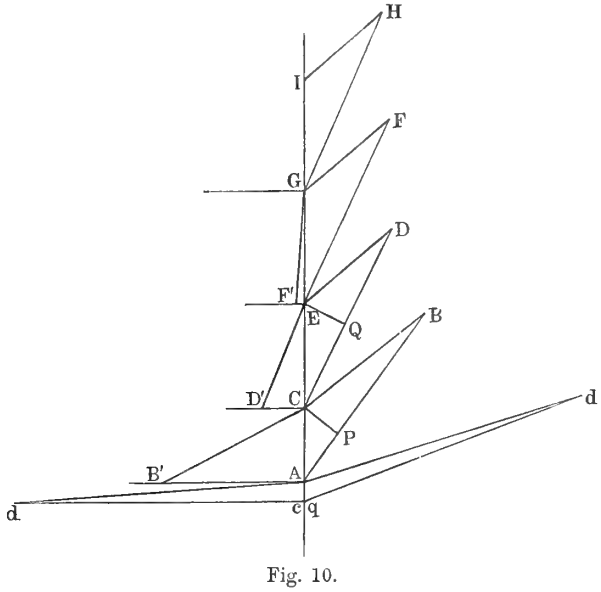

Fig. 10.

From this trigon CED we can, in the same way, that is, by making

EG = $\surd$(CE . ED), GF = $\frac{1}{2}$ (CE + ED), obtain a third trigon EGF ; and we can continue this series of trigons indefinitely. The ratio of CE to ED is much nearer to a ratio of equality than is AC : CB ; EG : GF is still nearer, and after a very few steps the ratio of say GI to IH becomes, sensibly, an equality. By continuing the progression in the opposite direction, that is, by making $Ad = CB + \surd(CB^2 - CA^2)$, $AC = CB - \surd(CB^2 - CA^2)$, we obtain trigons more and more scalene, the ratio of disparity of the two sides increasing with greater rapidity at each step. Hence of the general formula

$$dt \,.\, \surd 2g \;=\; \frac{d\mathrm{S}}{\surd (s^2 - r^2 \sin s^2)},$$

we can by continuing this series either way, render s equal to r, or greater or less than r in any enormous degree. The integration in these three cases must be considered separately.

In the first place, let us suppose that s, represented by cA, is infinitely small in comparison with r, represented by Ad. Here the arc S can never exceed a certain infinitesimally small limit, so that it may be held to be equal to its sine, and thus the formula becomes

$$dt \surd(2g) \;=\; \frac{d\mathrm{S}}{\surd (s^2 - r^2 \mathrm{S}^2)},$$

which is easily integrated, as in the familiar case of isochronous motions.

In the second place, when s, represented by Ad, is many times longer than r, or Ac, the velocity of the moving point being proportional to gd, may be held as constant; in which case the integral becomes $t \surd (2g) = \frac{\mathrm{S}}{s}$; this limit has been used in the previous paper. Both of these limits belong to the inverse progression, which leads directly to the result already explained. I shall, therefore, now direct attention to the third case, in which r and s have been rendered equal to each other.

The equation now becomes

$$dt \surd(2g) \;=\; \frac{d\mathrm{S}}{r \surd(1 - \sin \mathrm{S}^2)} \;=\; \frac{1}{r} \,.\, \sec \mathrm{S} \,.\, d\mathrm{S},$$

which has for its integral

$$t \surd(2g) \;=\; \frac{1}{r} \log \tan \left(\frac{\pi}{4} + \frac{\mathrm{S}}{2}\right);$$

so that if a heavy body be projected from the nadir-point of a circumference, with a velocity just due to a free descent along the diameter, the time in which it describes a given arc is proportional to the meridional part on Mercator's projection of the sphere corresponding to a latitude homologous with the half of that arc.

Thus, when we have continued the progression so far as to make GI = IH, the time in which the angle GFE has been generated can readily be found.

In order to obtain a perfectly clear idea of this scheme of approximation, let us draw through *c*, A, C, E, G, &c., lines perpendicular to CG, and inflect to these $Ad' = Ad$; $CB' = CB$, $ED' = ED$, &c.; then the angles *d'*, B', D', F' at the extremities of these are evidently the maximum values of *d*, B, D, F; and approach, toward the end of the series, more and more rapidly to a right angle.

Suppose that we wish to compute the time in which an arc of 6° is described, when the entire arc of oscillation is 7° to each side of the vertical line, the diameter of the circle being unit. Having made the angle $B'Ad' = 3^\circ\,..\,35'$, since it is the angle at the circumference subtended by the arc of oscillation, and measured $Ad' = \sqrt{\left(\frac{1}{\Delta}\right)}$, in this case *unit*, we draw *d'c* perpendicular to the horizontal line AB'; and then construct on the other side the trigon *cAd*, having $Ad = Ad'$, and $cdA = 3^\circ$; after which the formation of the series proceeds as already described.

The partial motion of the body through 6° of a total arc of 7° is now synchronous with another motion through an arc 2B of a whole arc 2B', but in a different circle; and lastly, it is synchronous with a motion through 2H°, when the body would just reach the zenith point of its circle. Hence the time would be expressed by $t\sqrt{2g} = \frac{1}{\mathrm{IH}}$. log tan $(45^\circ + \frac{1}{2}\,\mathrm{H})$. Hence the following scheme of calculation :—

*c*A =	·061 04854	8·785 6753	8·785 6753	° ′ ″ 3 30 00 = I'
A*d* =	1·000 00000	0·000 0000		
	1·061 04854	8·785 6753		
AC =	·247 08000	9·392 8376	9·668 1324	27 00 26 = B'
CB =	·530 52427	9·724 7052		
	·777 60427	9·117 5428		
CE =	·362 05235	9·558 7714	9·969 0427	68 37 21 = D'
ED =	·388 80213	9·589 7287		
	·750 85448	9·148 5001		
EG =	·375 18888	9·574 2500	9·999 7242	87 57 30 = F'
GF =	·375 42724	9·574 5258		
	·750 61612	9·148 7758		
GI =	·375 30806	9·574 3879	0·000 0000	90 00 00 = H'
IH =	·375 30806	9·574 3879		
Δ =	7·099 44	0·851 2242		

Here the data are $Ad = 1{\cdot}000$, $d' = 3^\circ\ 30'$; having written these in their places, and also the logarithm of *Ad* in the second column, the log sine of *d'*

in the third column, we take the sum of these, which is the logarithm of cA, and place it in the second column. The sums $cA + Ad$ and log cA + log Ad are next obtained. The half of the latter sum gives log AC, whence AC; the half of the former sum is CB, whence its logarithm. This very simple computation is repeated until we obtain GI and IH alike as far as our tables enable us to proceed. Log AC — log CB is written in the third column, it is log sin B′, whence we obtain B′, the maximum value of the angle B, and similarly for the others. The maximum value of H is 90°, that is to say, since this is the angle at the zenith point, the moving body would just describe the whole semicircumference from N to Z. We have thus computed all the dimensions of the diagram, fig. 10, on the left hand side of the line cI.

In order now to find the time in which the arc of 6° from the bottom of the circle would be described, we make $cdA = 3°$. Adding to the log sine of this the logarithm of $\frac{Ad}{Ac}$ we obtain log sin Acd, whence $Acd = 59° 00' 46''.9$ Half the sum of these angles is CAB; by adding to log sin CAB, log $\frac{Ac}{cB}$, or log sin B^1, we obtain log sin B, whence B. And thus we proceed until we come to $H = 21° 37' 38''$.

In the following scheme the calculations are given for the arc 6°, and also for the whole arc 7° :—

d =	3° 00′ 00″·00	8·718 8002	3° 30′ 00″·00	8·785 6753
		1·214 3247		1·214 3247
c =	59 00 46·90	9·933 1249	90 00 00·00	0·000 0000
A =	31 00 23·45	9·711 9215	46 45 00·00	9·862 3526
		9·668 1324		9·668 1324
B =	13 52 53·07	9·380 0539	19 49 46·30	9·530 4850
C =	22 26 38·26	9·581 8127	33 17 53·15	9·739 5685
		9·969 0427		9·969 0427
D =	20 49 29·60	9·550 8554	30 44 43·40	9·708 6112
E =	21 38 03·93	9·566 6532	32 01 18·27	9·724 4733
		9·999 7242		9·999 7242
F =	21 37 11·98	9·566 3774	31 59 56.40	9·724 1975
G =	21 37 37·96		32 00 37·34	
	90		90	
	111 37 37·96		122 00 37·34	
L. tan	55 48 48·98	= 0·167 9689	61 00 18·67	= 0·256 3407
Log log tan $\left(45 + \frac{H}{2}\right)$		= 9·225 2289		9·408 8176
Log nep tan 10		= 0·362 2157		0·362 2157
Colog IH		= 0·425 6121		0·425 6121
	1·030 520	0·013 0567	1·572 698	0·196 6454

To obtain a clear view of the import of these results, let us describe a series of circles all having the common nadir point N, and with diameters proportional inversely to the squares of A*d*, CB, ED, GF, IH, or, in the present example, proportional directly to the numbers 1·000, 3·553, 6·615, 7·095, and 7·099. Along these let arcs NU, NV, NX, NY, NZ, of 7°, 54° 01′, 137° 15′, 175° 55′, 180°, that is homologous to the doubles of the maximum angles *d*′, B′, D′, F′,

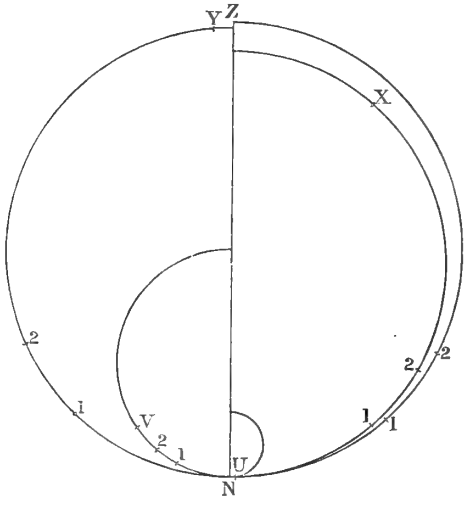

Fig. 11.

and G′ be laid off. Lastly, lay off arcs N^1, N^2 on each of these circles, homologous to the doubles of the angles at *d*, B, D, F, and H, as obtained by computation in the two cases. In the diagram, *fig.* 11, the semicircles only are drawn out; for the sake of clearness, they are placed alternately to the right and left of the common diameter NZ; also in the smallest circle the arc NU of 7° is also N^2, and N^1 is so close to it as not to be seen in the figure.

Let now a body be projected along the smallest circumference with a velocity which would just carry it from N to U, another along the second circumference with a velocity sufficient to carry it to V, a third body along the third circumference with speed enough to reach X, and so on. And imagine that all these bodies set off simultaneously from N, then will they all reach the points marked 1, 2 on the respective circumferences at the same instants. But when the velocity is just sufficient to carry the body to the zenith point Z, we can compute the time, and thus we are enabled to resolve our problem.

As there are no tables of neperian log tangents, we must convert the usual denary log tangents into neperian ones, by multiplying them by 2·3025, the neperian logarithm of ten. Hence the final computations shown in the preceding scheme; these give 1·030520 and 1·572698 for the values of $t\sqrt{(2g)}$, corresponding to arcs of 6° and 7° respectively.

Thus, by a very easily understood and by no means an operose process, we

are enabled to compute the time at which a heavy body moving along the circumference of a circle will reach a given point in it, when the velocity is insufficient to carry the mass over the zenith point.

The other case, when the body passes the zenith point, is resolved by considering the angles at *a*, A, C, &c. Thus, if we describe a circle having its diameter inversely proportional to the square of A*c*, and imagine a body to fall from a height greater than that diameter in the ratio of *d*A : A*c*, and to be projected along the circumference with the velocity so acquired, its motion would be represented by the variation of the angle A*cd*.

But this same investigation enables us also to resolve the converse problem: "to find the position of the body at any given instant," for since the time of describing any portion of the arc NZ, *fig.* 11 is proportional to a logarithmic tangent, we can easily compute the log tangent, and thence the arc corresponding to a given time; and having thus obtained the angle IHG of *figure* 10, we can deduce, by the operations of ordinary trigonometry, all the other angles, and thus the positions of the various bodies at the proposed instant on all the other circumferences can be found.

In retracing backwards the series of trigons, beginning with GIH, we must make IGF double of IGH, GED double of GEF, and so on; hence we must soon obtain an obtuse angle, the double of which would be a reverse angle, and it would seem as if our process failed. But in reality this reverse angle merely shows that the moving body has overpassed the zenith point, and has begun to descend along the other circumference, and thus our construction turns out to be absolutely general.

When one of the angles, as ECD of *figure* 10, becomes right, its double ECD becomes half a revolution, and so CAB and CBA become zeroes. Wherefore when the motion represented by the trigon CED has performed half of its period, the system typified by CAB has made a whole one. Thus at each step downwards along the series the periodic time is doubled; and if we wish to keep the same periodic time throughout, we must halve the dimensions of each successive trigon—an operation which brings us exactly to the conclusions obtained in the original paper.

XVII.—*On the Homological Relations of the Cœlenterata.*

By Professor Allman.

(Read 29th May 1871.)

Independently of the general agreement which necessitates the association of the *Hydra*, *Actinia*, and other Cœlenterate animals into one primary group of the animal kingdom, we must also expect a special morphological correspondence between the various forms of animals thus associated. In other words, a homological agreement ought to be determinable between the parts of animals included in any one subordinate section of the Cœlenterata with the parts of animals included in any other.

A comparison of the two primary sections of the Cœlenterata (*Actinozoa* and *Hydrozoa*), and of the various orders of these with one another, will show that such an agreement really exists, and that it is possible, by easily understood and thoroughly consistent modifications, to convert each special type into any of the others.

With the view of rendering apparent these relations, we shall compare an actinozoon (*Actinia*) with a hydrozoon (*Hydra*), and shall further compare with one another the various orders of the Hydrozoa.

Agassiz has compared the radiating chambers, which in an actinozoon intervene between the stomach sac and the outer walls, with the radiating canals of a medusa.* I believe that he has thus struck upon the true homologies of those parts; but when he maintains further that the differentiated stomach of an actinozoon is only the proboscis (hypostome) of a hydrozoon inverted into its body cavity, he suggests a conception of actinozoal homology which is inconsistent with the actual structure.

In order to form a correct notion of the homological relations between an *Actinia* and a *Hydra*, we have to imagine the tentacles of a *Hydra* (figs. 3, 4) for a greater or less extent connate with the sides of the hypostome and with one another. The hypostome of the *Hydra*, while retaining its normal position, will thus become the stomach of the *Actinia* (figs. 1, 2, *b*), and this will at the same time become connected with the outer walls by a series of radiating lamellæ—the connate tentacle-walls,—separated from one another by radiating chambers *a*—the cavities of the tentacles,—while such portions of the tentacles of the

* Contr. Nat. Hist. U.S. vol. iv. p. 377.

Hydra as still continue free will be represented by a single circle of the tentacles *a'* of *Actinia*.

Fig. 1.

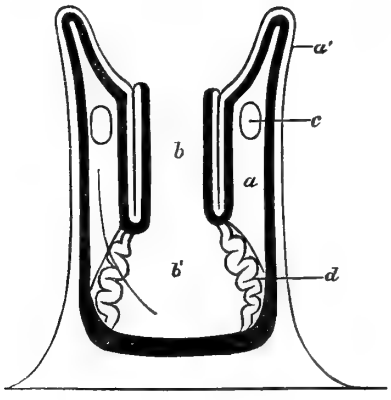

Fig. 2.

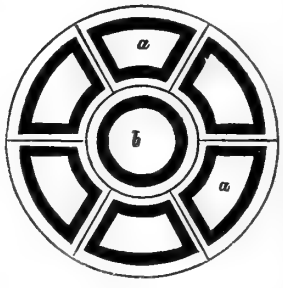

Fig. 1.—Diagramatic longitudinal section of *Actinia*. *a*, Radiating interseptal space ; *a'*, tentacle ; *b*, differentiated stomach-sac ; *b'*, somatic cavity ; *c*, aperture in radiating septa ; *d*, genitalia borne by radiating septa.

Fig. 2.—Diagramatic transverse section of *Actinia*. *a*, *a*, Interseptal spaces ; *b*, differentiated stomach-sac.

Having thus established a fundamental identity between the regions of an *Actinia* and of a *Hydra*, there will be no difficulty in recognising the relations between an *Actinia* and a hydroid medusa ; for, as I have elsewhere* attempted to prove, the tentacles of a *Hydra* are represented by the radiating canals (figs.

Fig. 3.

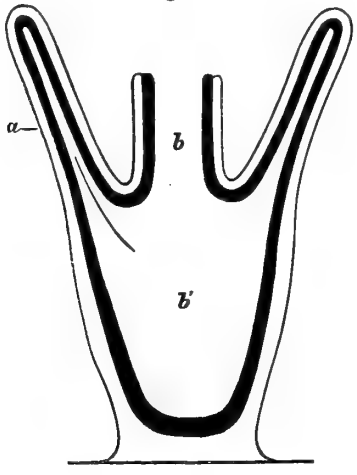

Fig. 4.

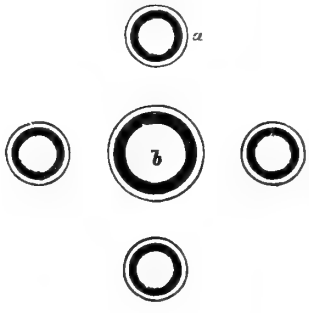

Fig. 3.—Diagramatic longitudinal section of *Hydra*. *a*, Tentacle; *b*, hypostome; *b'*, somatic cavity.

Fig. 4.—Diagramatic transverse section of *Hydra* through hypostome and tentacles. *a*, Tentacle ; *b*, hypostome.

5, 6, *a*), and those extensions of them (fig. 5, *a'*) which form the primary marginal tentacles of the medusa.

The distal ends of the radiating lamellæ in *Actinia* are perforated each by an opening (fig. 1, *c*), through which the radiating chambers communicate with one another. Agassiz has compared these openings to the circular canal

* Report on the Reproductive System of the Hydroida. Brit. Assoc. Report for 1863.

of a medusa, and I believe that in this view he has correctly expressed the relations in question.

If we further add that the generative apparatus is borne by the radiating

Fig. 5.

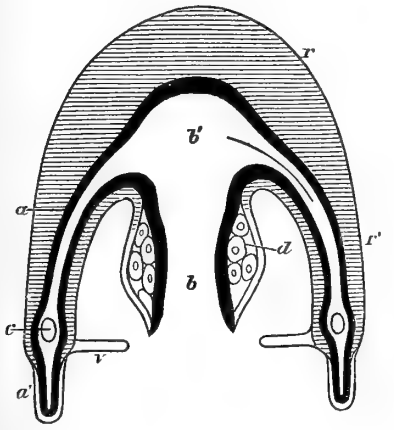

Fig. 6.

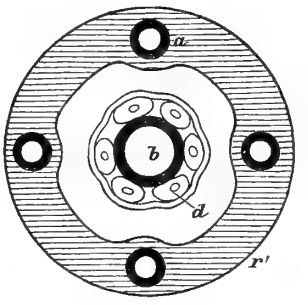

Fig. 5.—Diagramatic longitudinal section of a Hydroid Medusa. *a*, Radiating canal ; *a'*, marginal tentacle ; *b*, manubrium ; *b'*, atrium ; *c*, lumen of circular canal ; *d*, generative elements; *r*, atrial region of umbrella ; *r'*, manubrial region of umbrella ; *v*, velum.

Fig. 6.—Diagramatic transverse section of Hydroid Medusa through the manubrial region of the umbrella. *a*, Radiating canal ; *b*, manubrium ; *d*, generative elements ; *r'*, manubrial region of umbrella.

partitions, we shall have all the leading points in the morphology of an actinozoon.

A comparison of the various orders of the Hydrozoa with one another will result in the detection of close homological correspondencies, and will throw important light on the morphology of each.

Between a siphonophore and a hydroid the homology is so obvious as to be instantly recognisable. The siphonophore (fig. 7), as well as the hydroid, presents us with a colony of zooids, kept in organic union with one another by means of a common connecting basis or cœnosarc ; but this cœnosarc, instead of being fixed, as in the HYDROIDA, is in the SIPHONOPHORA invariably free, and provided with a special apparatus for natation.

In consequence of the great extent to which heteromorphism is carried among the zooids composing a siphonophoral colony, we can scarcely institute a satisfactory comparison between the two orders without determining the homologies of each kind of zooid in the siphonophore. Beginning with the polypites or alimentary zooids (*e*) of the siphonophore, and comparing these with the hydranths of a hydroid, we shall find the two forms to agree in almost every point, except in the number and position of the tentacles, which in the siphonophore are reduced to a single one (*f*), springing, in all the typical SIPHONOPHORA, from the base or proximal end of the polypite. The branched condition of the tentacle in the siphonophore is in no respect inconsistent with this comparison ; and even if it were necessary to find a parallel to it among the HYDROIDA, we should have this in the branching tentacles of *Cladocoryne*.

The hydrocysts (*g*) of the siphonophore are plainly arrested polypites, in which the mouth has never become developed.

Again, the generative zooids (*i*) are exactly paralleled by those of the HYDROIDA, and are, like them, referable to two types, expressed in the Hydroida by the phanerocodonic and the adelocodonic gonophores, the situation of the generative elements being precisely similar in the two orders; while the nectocalices or locomotor zooids (*k*, *k*) are essentially hydroid medusa, with specially developed umbrella, but with the manubrium suppressed, and the somatic cavity reduced to the atrium, from which spring radiating canals, which, exactly as in the hydroid medusa, open round the margin into a circular canal.

Fig 7.

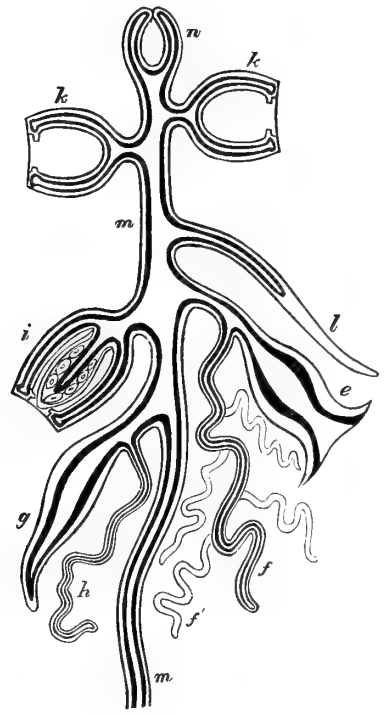

Fig. 7.—Diagram of a Siphonophore. *e*, Polypite; *f*, tentacle springing from proximal end of polypite; *f'*, branches given off by the tentacle; *g*, hydrocyst; *h*, tentacle of hydrocyst; *i*, generative zooid representing the phanerocodonic gonophore of a hydroid; *k*, *k*, nectocalices; *l*, bract; *m*, *m*, cœnosarc; *n*, pneumatocyst.

The bracts or hydrophyleia (*l*) of the siphonophore are essentially cæcal offsets from the common canal of the cœnosarc, but with the ectoderm greatly developed and modified, as in the umbrella of a medusa, so as to fit them to become organs of protection for the other zooids. They have thus essentially the same morphological foundation as the nectocalices, but, with a different functional destination, diverge widely from these, and constitute an apparatus of protection instead of locomotion.

All these zooids are kept in union with one another by a cœnosarc (*m*, *m*), which, in the typical SIPHONOPHORA, is filiform, with an axial canal in free communication with the cavity of each of its appended zooids, thus corresponding essentially with the filiform tubular cœnosarc of a hydroid colony; while in the somewhat aberrant forms with fusiform or discoidal cœnosarc (*Physalidæ*, *Velellidæ*), an obvious comparison is suggested with the appressed expanded cœnosarc of *Hydractinia*.

From the hydroid cœnosarc, indeed, that of the SIPHONOPHORA mainly differs in the absence of an external chitinous sheath, and in its free mode of existence, the siphonophore dwelling at large in the open sea, through which, in the great majority of the order, it is propelled by the contractions of the nectocalices. In the siphonophorous section, *Physophoridæ*, the proximal extremity of the cœnosarc, instead of forming, as in the Hydroida, a hydrorhiza for fixation, is modified by an inversion of its

walls, so as to constitute an air-filled chamber (pneumatocyst) (*n*), which acts as a float.*

Continuing to take the HYDROIDA as a standard of comparison, the other hydrozoal orders may be now contrasted with them. If the atrium, or that portion of the somatic cavity (fig. 5, *b'*) which lies at the base of the manubrium in a hydroid medusa, be expanded laterally, and the ectoderm of its floor be projected along four or eight symmetrically disposed radiating lines into as many thick pillars (figs. 8 and 9, *o*, *o*), which converge towards the axis, and there meet the manubrial extension of the cavity, while the thin intervening portions of the floor between the pillars become developed into generative pouches (*d*), and the velum or perforated diaphragm, which stretches across the codonostome in the hydroid, disappears, we shall have the hydroid medusa converted, in the more essential points of its structure, into a discophorous medusa (figs. 8, 9).

Again, a *Lucernaria* (figs. 10, 11) may be conceived of by imagining a *hydra*

Fig. 8.

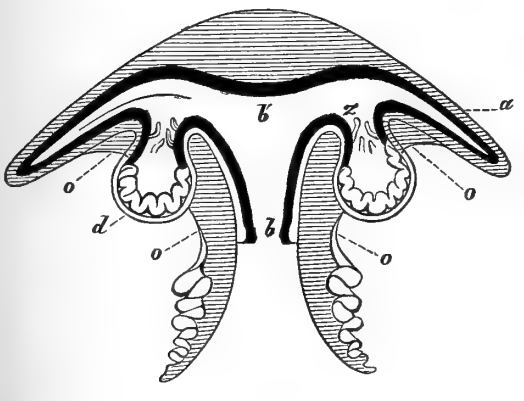

Fig. 9.

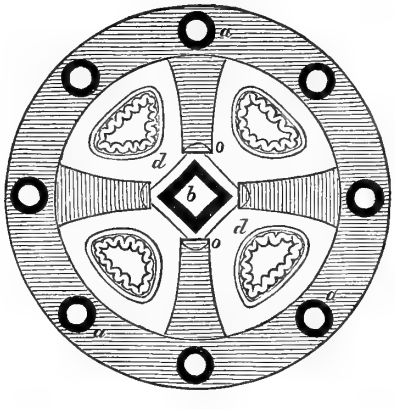

Fig. 8.—Diagramatic longitudinal section of a Discophorous Medusa. *a*, Radiating canal; *b*, manubrium; *b'*, somatic cavity; *d*, generative pouches; *o*, *o*, *o*, pillar-like extensions of the oral side of the umbrella; *z*, tentacula-like processes of the inner surface of the somatic cavity.

Fig. 9.—Diagramatic transverse section of a Discophorous Medusa. *a*, *a*, *a*, Radiating canals; *b*, manubrium *d*, *d*, generative pouches; *o*, *o*, umbrello-manubrial pillars.

with four tentacles to have these tentacles expanded laterally, until their sides meet and coalesce, the hypostome still continuing free, and the proximal portion of the body becoming extended into a solid peduncle of attachment, containing a simple prolongation of the somatic cavity, or traversed longitudinally by four narrow prolongations of this cavity, while generative sacs become developed on each side of the partitions formed by the coalescent sides of the tentacles.

* In the above comparison of the siphonophora with the hydroida, I have adopted for the siphonophora the terminology proposed by HUXLEY, whose views of the homological relations existing between the two orders I have also generally followed. See his "Oceanic Hydrozoa," page 8, &c.

Lastly, the CTENOPHORA (figs. 12, 13) admit of an obvious comparison with a hydroid medusa. In order to understand this, we must keep in mind the presence in the hydroid medusa of an *atrial segment* of the somatic cavity. This is formed by that portion of the somatic cavity which is immersed in the substance of the umbrella at the base of the manubrium, and from which the radiating canals proceed (fig. 5, *b'*). The hydroid medusa thus admits of a division, by a transverse plane, into two regions: an *atrial region* (*r*), which corresponds to the solid summit of the umbrella with the parts therein contained, and a *manubrial region* (*r'*), which corresponds to the manubrium, with that portion of the umbrella which with its associated structures is projected round the manubrium in the form of a bell.

Now, in a *Beroe* (figs. 12, 13), the manubrial region is never developed, and the body is represented by the atrial region alone. From the atrium (*b' b'*) con-

Fig. 10.

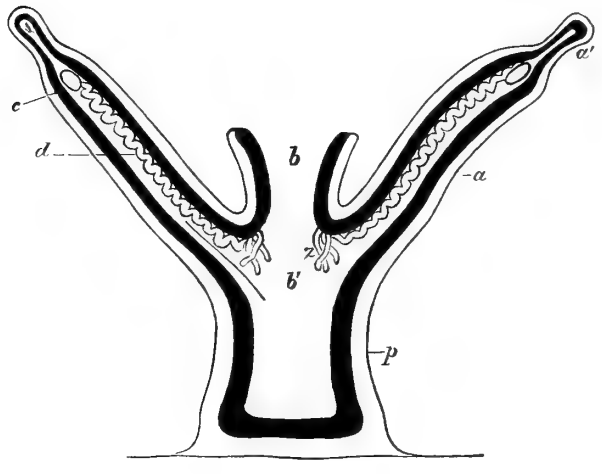

Fig. 11.

Fig. 10.—Diagramatic longitudinal section of *Lucernaria*. *a*, Circum-oral disc; *a'*, marginal tentacle; *b*, hypostome; *b'*, somatic cavity; *c*, aperture by which the chambers of the circum-oral disc communicate with one another across the distal end of the partition; *d*, generative bands; *p*, peduncle; *z*, tentacle-like processes of the inner surface of the somatic cavity.

Fig. 11.—Diagramatic transverse section of *Lucernaria* across the circum-oral disc and hypostome. *a*, *a*, Chambers of the disc; *b*, hypostome; *d*, generative bands.

tained within this region two radiating canals (*a*, *a*) are given off. These immediately divide and subdivide, so as to become ultimately eight, which are, moreover, united at their distal extremities by a circular canal, which corresponds to that of the medusa, though here thrown back by the non-development of the manubrial region of the umbrella. Besides the eight longitudinal canals (*x*, *x*) into which the two radiating canals ultimately subdivide, these two canals give off, each immediately after its origin, an accessory canal (*x' x'*), which runs without division close to the main body cavity towards the oral orifice, and opens, like the others, into the circular canal.

The generative sacs (*d'*, *d*) are developed as diverticula along the course of the radiating canals, whence they extend into the gelatinous substance of the body.

Leuckart insisted on the association of the Ctenophora with the Actinozoa rather than with the Hydrozoa, and the same view of their affinities has been advocated by Huxley. According to this conception of ctenophoral homologies, the ctenophore must be provided with a stomach-sac, differentiated, as in the actinozoon, from the general body cavity. Now, though the somatic cavity in *Beroe* suddenly diminishes towards the aboral end, and is there provided with a pair of valve-like folds (fig. 12, *s*), so that the entire tract admits of being distinguished into two regions, it is nevertheless as continuous and simple as in Hydra.

The advocates of the actinozoal nature of the Ctenophora see in the canal system of a *Beroe* or a *Cydippe* the radiating chambers of an *Actinia*, separated from one another by partitions of relatively enormous thickness. I do not desire to dispute the correctness of this view. We have already compared a

Fig. 12.

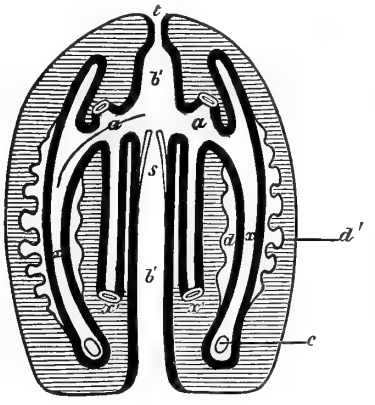

Fig. 13.

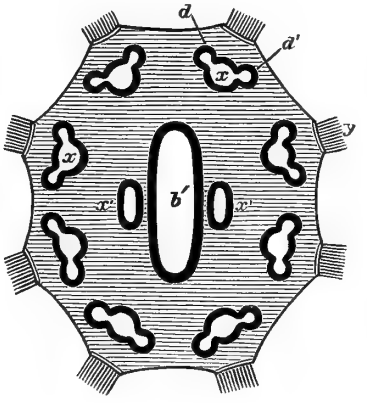

Fig. 12.—Diagramatic longitudinal section of *Beroe* in a plane at right angles to that of the compressed somatic cavity. In order to give a sufficiently comprehensive view of the structure, a few parts are here represented, which are in reality somewhat removed from the plane of the section. *a*, *a*, Transverse portion of the radiating canal system, two of the primary branches being shown as if cut off close to their origin; *x*, *x*, meridional portion of this system; *x' x'*, deep or accessory canals, their distal ends cut off; *b' b'*, somatic cavity; *c*, lumen of circular canal; *t*, one of the aboral outlets of the somatic cavity; *b' b'*, somatic cavity; *t*, external opening of one of the aboral canals; *s*, valve-like processes of the inner surface of the somatic cavity; *d*, *d'*, generative sacs, male and female.

Fig. 13.—Diagramatic transverse section of *Beroe*. *b'*, Somatic cavity; *x*, *x*, meridional portion of the radiating canal system; *x'*, *x'*, deep or accessory canals; *d*, *d'*, generative sacs, male and female; *y*, vibratile lamellæ.

hydroid with an actinozoon, and have seen in the radiating canals of a hydroid medusa the homologues of the radiating chambers of an actinia; so that, even though the Ctenophora be truly Hydrozoa, we must expect to find in them the same points of agreement with the Actinozoa which we have endeavoured to demonstrate for the other hydrozoal orders.

Now, the fact of the radiating canals being widely separated from the axial cavity instead of being adnate to it, is exactly the point which essentially distinguishes a hydrozoon from an actinozoon; and the fact of the intervening space being in the ctenophore obliterated by the interposition of a voluminous gelatiniform mass does not alter this relation, for it is exactly what we find in

the atrial region of an ordinary hydroid medusa, while it is distinctly expressed in the gonophore of *clavatella*, where the free or manubrial region of the umbrella is rudimental, and the whole gonophore, apart from the marginal tentacles, becomes comparable to the atrial region of an ordinary hydroid medusa.

The accessory canals of *Beroe* run, it is true, close upon the walls of the axial cavity until they leave these to throw themselves into the circular canal; but this fact cannot, in opposition to the greatly preponderating hydrozoal features of *Beroe* be used as an argument for the actinozoal nature of the CTENOPHORA.

The accessory canals are not represented in the hydroid, while the *Beroe* further differs from the hydroid in the presence of the two short aboral canals, by which the aboral end of its somatic cavity communicates with the outer world (fig. 12, *t*), as well as in the disposition of its so-called nervous system and sense organs, and in its characteristic bands of vibratile lamellæ (fig. 13, *y*); all which features are among the special characteristics of the order, and in no way justify the absorption of the CTENOPHORA into the ACTINOZOA.

In this attempt to determine the true affinities of the CTENOPHORA, I have taken *Beroe*, instead of *Cydippe* or other ctenophorous genus, as the subject of comparison, not only because *Beroe* is a typical ctenophorous form, and of comparatively simple structure, but because I have myself made its anatomy and development a subject of special study.*

* Proc. Roy. Soc. Edinb., 1862.

XVIII.—*On the Gravid Uterus and on the Arrangement of the Fœtal Membranes in the Cetacea.* Plates XVII. and XVIII. By Professor Turner.

(Received 20th March 1871.—Read 3d April).

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The distinguished French naturalist, Professor H. Milne Edwards, in the ninth volume of his valuable Lectures on Comparative Anatomy and Physiology, published only last year, when referring to the fœtal membranes in the Cetacea, states, that much information is still required to complete our knowledge of that subject.*

It may perhaps be advisable, before I commence to describe the results arrived at by my recent dissections, to give a brief account of the observations made by previous inquirers into this department of anatomy, so that we may more clearly recognise wherein our deficiencies lie, and the direction in which our researches ought to be conducted, in order to render our information as complete as possible.

Karl Ernst von Baer in his celebrated memoir, "Ueber Entwicklungsgeschichte der Thiere,"† says, "I know nothing of the ovum of the cetacea from my own observations; the scanty notices which we find on this subject in anatomical literature at least show that there is no definite placenta, and lead us therefore to suppose that the ovum is similar to that of the pachydermata."

D. F. Eschricht in an academic dissertation, published in the same year as Von Baer's memoir, recorded the dissection "*Delphini phocænæ gravidi.*"‡ He described the free surface of the uterine mucous membrane as rugose, cellular, and cribriform. The surface of the chorion was strongly marked by rugæ, which could not be obliterated. Almost the whole surface was covered by villi, which were separated from each other by intervals of nearly half a line. The villi possessed narrow stalks, and their free ends expanded into a globular branching crown, like the head of a cauliflower. In the hollows between the rugæ very small villi were found. A beautiful capillary network was situated within the crowns of the villi. The villi were adapted to the little recesses or

* Leçons sur l'anatomie comparée, vol. ix. note, p. 563. Paris, 1870.

† Second part, p. 257. Königsberg, 1837.

‡ De organis quæ respirationi et nutritioni fœtus mammalium inserviunt. Hafniæ, 1837.

cells seen on the surface of the uterine mucous membrane, which surface was very vascular. He also observed a layer of branching uterine glands, which were so numerous and so closely set together that it was difficult to trace out single specimens. The mouths of these glands opened into areolæ on the uterine mucous surface, and he believes that their secretion is taken up by the veins of the villi of the chorion, which are in apposition with these mouths, and that the nutrition of the fœtus is sufficiently provided for by the absorption of this secretion.

Professor Owen, in a note to John Hunter's description of the parts of generation of the cetacea,* states that the allantois is co-extensive in its development with the chorion, and that both extend into the horns of the uterus. The fœtus has neither placenta nor cotyledons; but, as in the hog and camel, the general vascularity of the chorion is subservient to its nutrition and respiration. In a foot-note on a previous page (70), he had characterised the placenta in the sow and the mare as diffused over nearly the whole surface of the chorion. In the catalogue of the comparative anatomy specimens in the Museum of the College of Surgeons,† he mentions the presence of pedunculated corpuscles of the amnios on the umbilical cord of a fœtal dolphin (*D. delphis*).

Dr C. D. Meigs, in the course of some observations on the reproductive organs and the fœtus of *Delphinus nesermak*,‡ observed the plicated arrangement of the uterine mucous membrane, and of the corresponding surface of the chorion, the projections and sulci of the one being accurately adapted to the sulci and projections of the other, so that the real surface of contact very much exceeded the apparent surface. The fœtus was developed in the left uterine cornu, which was larger than the right, though the latter was partially developed by the intrusion into its cavity of the chorion and allantois. The amniotic outgrowths are figured on the umbilical cord, but are not described.

Professor Rolleston also directed attention to the prolongation of the membranes of a solitary cetacean embryo,§ which he had examined, "from one cornu round into the other, and projecting by a cœcal extremity into a short corpus uteri." He observed and described filiform outgrowths of the amnion, where it invested the umbilical cord, and pointed out that the cornual ends of the cetacean membranes were bare and glabrous as compared with the villous character of the rest of the chorion.

* Collected works, Palmer's Edition, vol. iv. p. 390. 1837.

† Vol. v. p. 200. 1840. Comp. Anat. of Vertebrates, vol. iii. p. 732.

‡ Journal Academy Natural Sciences of Philadelphia, 1849, vol. i. p. 267. I have not seen this paper, and am indebted to my friend Dr Rolleston for the above abstract of its contents. In a paper in the Proceedings of the same Academy, vol. iv., 7th August 1849, Dr Meigs related some experiments made to ascertain the effects of deep-sea pressure on the uterus of the cetacea.

§ Trans. Zool. Soc. 1866, v. p. 307. The species was not determined.

In the account, necessarily very imperfect, owing to the greatly injured condition of the membranes, which I gave of the chorion in the Longniddry whale (*Balænoptera Sibbaldii* *), I described the folds and ridges of the chorion, the villous character of its surface, and the presence of at least one well-defined spot free from villi. Like my predecessors, I was unable to determine the relations of the amnios and allantois to each other and to the chorion. In the present communication I hope to be able to supply not only these, but other important blanks in our knowledge of the arrangement of the fœtal membranes in this interesting group of mammals.

In the early part of February of the present year, a shoal of whales entered Bressay Sound, Shetland, on the cessation of a heavy storm, which had raged for many hours. The fishermen at once started in pursuit, and succeeded in driving the shoal ashore in a bay to the north of Lerwick, with the exception of one specimen, which sank before it reached the beach. The animals stranded were eighteen in number.

Through the great courtesy of Mr James Gatherer, collector of customs in Lerwick, a gentleman well known to many naturalists as a careful and zealous observer, I have not only learned the following interesting particulars respecting these animals, but have also had the good fortune to receive the gravid uterus of a pregnant female. Mr Gatherer writes, "The animals ranged in length from 17 feet to 24 feet. The Shetlanders call them the 'spotted caaing whale,' or the 'fleckit whale,' or the 'pict whale,' and in one locality the 'Lupster,' a term which has a Norse sound, and is possibly of Norse origin. Though 'caaing' (driving) whales, yet they are not the common 'caaing' whales of the Shetlanders (*Globiocephalus deductor*). The more prominent dorsal and the shorter pectoral fins, the less rounded head and muzzle, and the piebald colour, show a marked difference between them and the 'caaing' whales, so frequently and in such large numbers driven ashore on the Shetland coast. I suppose it will be found that they were the Grampus (*Phocæna orca*). The Shetlanders know very little about them, although small herds have on several occasions been driven ashore in different voes throughout the islands. It is seldom so many or so large specimens are driven. The natives consider them far more active, wary, and dangerous than the 'caaing' whale. They tell me a few are sometimes seen mingled with a herd of the 'caaing' whales, on which occasions they fail to drive the latter. They attribute their escape to the superior retreating tactics of their more wide-awake congeners, who take the lead.

"I laid open the stomachs of two of the animals with the hope of finding some evidence of the nature of their food, but with the exception of a large number of worms, and some green frothy matter, the stomachs were empty. We found a fœtus lying on the beach which some of the flensers had extracted

* Proc. Roy. Soc. Edinburgh, 20th December 1869, and Transactions for 1870.

from the womb. Observing another female in an apparently 'interesting condition,' we got one of the men to make a longitudinal opening in the abdomen, which exposed a gravid uterus of large dimensions. To render the transmission of the parts safer, I ran off the uterine liquor before packing the uterus in a barrel. I found the number of teeth on each side of each jaw to be eleven, or forty-four in all. The teeth of many, I suppose the adults, were quite flat, or entirely worn down until flush with the gums. When this was not the case, they were of considerable length, and the teeth of one jaw fitted into the intervals between the teeth of the jaw opposed to it."

From the examination of the fœtus, and of the skull of one of the adult animals, I can substantiate the supposition of Mr GATHERER, that these animals were Orcas. By recent systematic writers the Orca, or Killer Whale, is no longer included within either the genus *Grampus*, or *Delphinus*, or *Phocœna*, with one or other of which it had been associated by many naturalists. The special characters which it exhibits are now considered to have a generic value, and the name *Orca gladiator* is applied to this creature.

I shall now pass to the description of the specimen, and shall consider—1*st*, the uterus and appendages; 2*d*, the fœtal membranes; 3*d*, the position and general form of the fœtus; 4*th*, a comparison of the cetacean form of placentation with that of other mammals.

The Uterus and Appendages.—The uterus consisted of a cervix, a corpus, and of two cornua (Plate XVII. fig. 1). The various subdivisions of the organ were invested by a continuous layer of strong peritoneal membrane, which extended in a broad double fold from the concave border of each cornu to the side and surfaces of the cervix uteri. The cervix was 7 inches long, and the corpus uteri 14 inches. The two cornua curved outwards from the body, which seemed indeed to bifurcate at its anterior border into the two horns. The left horn, about twice the size of the right, measured, along the convexity of the curve, 6 feet 7 inches from the angle of bifurcation to the junction of the tip of the horn with the Fallopian tube. The right cornu, along the corresponding border, measured 3 feet 6 inches. The greatest breadth of the left cornu was 19 inches, of the right 9 inches.

A strongly muscular "ligamentum rotundum," flattened at the sides, was attached to each horn, 3 inches from its free end, and lay in relation to the inferior part of the broad ligament. Each horn terminated in a well-defined Fallopian tube, upwards of one foot in length, which lay in the free margin of the broad ligament, and terminated externally in a widely dilated trumpet-shaped mouth, the wall of which was formed of a duplication of the peritoneum. The dilatation was so wide that the entire ovary could be included within it. Immediately on the uterine side of this mouth was an elongated, deep, pouch-like recess, formed by a folding of that part of the broad ligament which

extended between the Fallopian tube and the root of the ovary. Numerous tortuous blood-vessels accompanied the Fallopian tube, branches from which ramified between the layers of peritoneum which surrounded the mouth of the tube. When these vessels were turgid with blood, the otherwise lax membrane would doubtless have become tense, and capable of being accurately adapted to the surface of the ovary. The lumen of the tube was throughout so large that a full-sized catheter could be passed along it. Its mucous lining was elevated in longitudinal folds, continuous at the uterine end with folds to be afterwards described in the mucous membrane of the cornu. At the opposite end, where the mucous lining of the tube became continuous with the serous membrane surrounding the mouth, the folds diverged from each other, and then passed outwards as foldings of the serous membrane, along the inner surface of the trumpet-shaped mouth, as far as its free edge.

The left ovary had been removed before the specimen came into my possession. The right ovary, about the size of a duck's egg, was attached to the uterine cornu by its proper ligament. It lay in relation to the upper surface of the broad ligament, with which it was connected by a mes-oarium 3 inches in depth by $3\frac{1}{2}$ inches in breadth, so that it could be freely removed to and fro. Between the folds of the mes-oarium numerous blood-vessels passed to and from the gland, and close to the hilum was a flattened body $2\frac{3}{4}$ inches long by $1\frac{1}{2}$ inch in its greatest transverse diameter, the relation of which to the ovary reminded one of that of the epididymis to the testicle. The ovary was somewhat flattened at the sides, and presented near the free convex surface a linear, slightly puckered depression, which was in all probability a cicatrix. In other respects the outer surface of the ovary was smooth, and its investing membrane was continuous with the mes-oarium. Beneath this membrane, an abundant venous plexus, which was readily injected, and through which the injection passed freely into the veins within the ovary and the flattened body at its hilum. A vertical mesial section was then made through the ovary and the flattened body. The latter was found to be composed of a close plexus of dilated and tortuous veins and arteries imbedded in a dense connective tissue. The ovary itself appeared to be completely occupied with a large corpus luteum, which was 3 inches long by 2 inches broad. It possessed a strongly marked central cicatrix, much broader at one end than the other, which measured 1·8 inch in length (fig. 2). From this cicatrix numerous slender bands radiated into the corpus luteum, which possessed the characteristic yellow colour. Owing to the great size of the corpus luteum, the proper ovarian substance was not at first recognised, and it was only after a number of thin sections had been made and examined under the microscope, that the ovarian stroma, pushed entirely to the periphery of the ovary, and forming a sort of capsule to the yellow body, was detected. In many parts of the periphery the stroma formed little more than

a connective tissue envelope for the larger superficial arteries and veins, but elsewhere it was not so compressed, so that a distinct layer of stroma substance was more readily recognised, from which processes passed between the subdivisions of the corpus luteum. In these processes small arteries and veins were situated, which entered the yellow body, and formed in it a capillary plexus. This plexus extended as far as the margin of the central cicatrix, where it was much less abundant than in the peripheral portions of the corpus luteum. It formed a beautiful polygonal network, the meshes of which were occupied by the characteristic fusiform cells of the corpus. Some of these cells were unicaudate, but others were split into several processes at their opposite ends (fig. 3). The corpus luteum was much more vascular than the ovarian stroma, in which latter numerous dumb-bell shaped bodies were seen.

The vagina was 16 inches in length, and 8 inches in breadth. It possessed a thick muscular coat, and its mucous membrane was elevated into the powerful folds, corrugated on the surface, which are so well-known in the interior of this tube in the cetacea. The bladder was closely attached to the anterior wall of the vagina, about 4 inches behind the cervix. It was pyriform, and received on each side a large ureter, which ran obliquely through the muscular coat, before it opened into the bladder. A well-defined urethra, partially imbedded in the inferior wall of the vagina, ran backwards, to open immediately in front of the vaginal orifice. The posterior surface, summit, and sides of the bladder were covered by peritoneum, which was prolonged on to the cervix uteri, whilst it left the bladder at the summit, along the line of the slender obliterated urachus.

At least twenty arteries, about the size of the human brachial and ulnar, but the coats of which were relatively thicker, lay between the two layers of each broad ligament, close to the side of the cervix uteri. They ran forward, diverging somewhat from each other, to the cornu, and in their course did not present the tortuous arrangement found in the arteries of the human gravid uterus. A few small collateral branches arose from them, which passed to the tissue of the broad ligament, and here and there an obliquely-extending anastomosing branch united adjacent arteries. At some part of its course each artery bifurcated, and where these branches reached the uterine horn, some extended forwards on one surface, others on the opposite. The branches now became more frequent, and on the convex border of the horn, the branches for the opposite surfaces freely anastomosed with each other. Those arteries which lay nearest to the cervix and corpus uteri entered their substance, and, like the arteries of the cornua, subdivided in the muscular wall. Numerous veins were seen to accompany the arteries, and these again were neither tortuous nor dilated into venous sinuses, such as one sees in the pregnant human uterus. Nerves, also,

some of which were larger than the great splanchnic nerve in man, accompanied the arteries in their distribution.

When the uterine cornua were opened into, their walls were seen to be not more than from $\frac{1}{4}$ to $\frac{1}{2}$ an inch in thickness; their cavities contained the bag of fœtal membranes, and in that part of the bag which lay in the left cornu a good sized fœtus had formed. The fœtal membranes had become detached from the uterine mucous surface, and could be readily drawn out of the uterine cavity. The two cornua did not communicate with each other so freely in the corpus uteri as might have been supposed from the external examination of that part; for a vertical fold of mucous membrane, 8 inches in length, the posterior border of which was sickle-shaped and free, formed a mesial septum between the two horns at the anterior part of the corpus; and the orifice of communication between them, which was situated in immediate relation to the os uteri internum, was not more than about 5 inches in diameter.

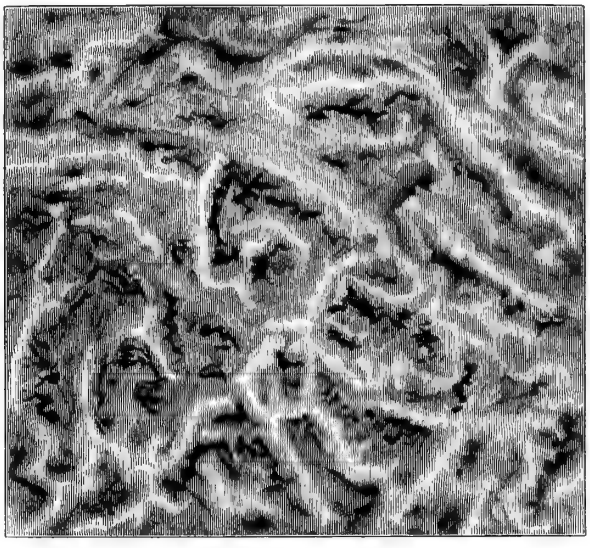
The mucous lining of the cornua had a reddish-brown colour. Its general characters did not quite correspond on the two sides. In the right smaller cornu the mucous membrane, near the funnel-shaped passage into the Fallopian tube was elevated into strong succulent folds, which projected from half-an-inch to an inch beyond the general plane of the mucous membrane. These folds starting from the oviduct, as from a centre, slightly diverged from each other, as they passed parallel to the long axis of the horn towards the corpus uteri, and at the same time gradually subsided, so as almost to have disappeared where the cornu joined the body of the uterus (fig. 1). On closer examination each fold was seen to be subdivided into multitudes of ridgelets, with narrow separating furrows, which lay almost parallel to each other, and in the direction of the main fold.

In the large impregnated cornu, the folds were only distinctly visible at the free narrow end of the horn, for they soon subsided to the common plane of the uterine mucous membrane, in all probability owing to the great distension of this cornu. But their original position and direction were marked on the surface of the membrane by parallel lines, which obviously represented the ridgelets previously referred to.

The vertical fold of mucous membrane, already described as forming an imperfect mesial septum between the two cornua, was continued along the inferior and superior walls of the corpus uteri, close down to the os internum, and a number of folds of mucous membrane from the inner end of each horn converged to the same orifice. The mucous membrane of the os itself was arranged in distinct and almost parallel laminæ, which projected into the cervix uteri. The orifice was filled up with a plug of very viscid and strongly smelling mucus. The lining membrane of the cervix uteri did not show an *arbor vitæ*, but simple longitudinal parallel folds, not so prominent as those of the os internum.

These folds reached as far as the os externum, the orifice of which was sufficiently large to admit a good-sized orange. The wall of the cervix was half an inch thick.

When the free surface of the mucous membrane of the uterine cornua was examined with the naked eye in a good light, under either water or spirit, it was seen to possess a delicate reticulated character. The strands of the network were formed of slender bands of the mucous membrane, many of which ran parallel, being connected at intervals by shorter transverse or oblique bars; whilst others, again, had a much more irregular arrangement. Small recesses, or pits, or furrows opened on the surface of the membrane, between these bands or bars, and sank some depth into its substance. By the use of low



Surface view, under a low power of the microscope, of a portion of the uninjected uterine mucous membrane. The recesses, furrows, and pits, into which the pockets or crypts open, are darkly shaded in the figure.

magnifying powers these recesses could be more accurately studied. Sometimes they formed elongated furrows, which were again subdivided by more delicate bands of the mucous membrane into smaller crypt-like compartments, which opened freely into the furrow. In other localities the recesses were irregular polygonal pits, and sometimes even ovoid or circular in form. These also, like the furrows, were subdivided into a variable number of crypt-like compartments. In some places the recesses were so closely crowded together that the surface of the mucous membrane had a honeycomb appearance, but in others comparatively broad patches of membrane separated a cluster of recesses and crypts from those which lay around. As a rule, the body of each crypt was more dilated than its mouth, and the crypts formed little pockets or pouches for the reception of the club-shaped processes of the chorionic villi.

The complete absence of any putridity led me to hope that a minute injection of the vessels of the mucous membrane might be obtained, and that the relation of the capillaries to the crypts and to the uterine glands might be studied. Injecting pipes were accordingly inserted into some of the uterine arteries, and, with the skilled aid of my assistant, Mr STIRLING, the uterine system of capillaries was successfully filled with a gelatine and carmine injection. But before I enter on an account of the distribution of the blood-vessels, it will be necessary to point out the characters of the mucous membrane itself, as displayed both in vertical sections, and in horizontal sections made parallel to the plane of the free surface.

Vertical sections through the membrane confirmed the description just given of the arrangement of the pits, recesses, and crypts already recognised by the inspection of the free surface. The depth of the crypts was variable, but in no instance did they seem to occupy more than about the superficial third of the thickness of the mucous membrane, and those which passed deepest into its substance had usually several shallower crypts grouped around them. The form of the deeper crypts resembled more a funnel, that of the shallower a cup. It may be convenient to call this part of the membrane the crypt-layer (*a*, fig. 4), or perhaps, from its numerous capillaries, the vascular crypt-layer.

The deeper two-thirds contained numerous elongated tubular glands—the proper utricular glands—and may appropriately be called the glandular-layer (*b*, fig. 4). It lay in contact with the muscular coat. From their tortuous course and direction, the individual glands could only be followed for a comparatively short distance, and they presented different appearances in the vertical and horizontal sections. As their long axes lay mostly in a direction parallel to the free surface, good views of their arrangement were obtained in the horizontal sections, in which the glands were seen not only to be convoluted, but to branch (fig. 5). Sometimes they bifurcated, at others three branches arose close together, and the branches could be traced sometimes for a considerable distance, but at others they formed short diverticula closed at their free ends. Each branch possessed throughout an almost uniform diameter, but the portion of the gland-tube situated immediately beneath the crypt layer, which may be called the stem of the gland, had a wider calibre than its various branches, which lay in the deeper portion of the mucous membrane. In the vertical sections, again, as a rule, only short lengths of any given gland could be traced, for the tubes were divided, sometimes longitudinally, but not unfrequently obliquely or transversely (fig. 4, *b*). As it was of importance to ascertain the relations of the glands to the crypts, I examined many vertical sections to see if I could follow the stems of the gland tubes, through the thickness of the mucous membrane, to their openings or mouths on the free inner surface of the uterus. And in carrying on these observations I encountered considerable

difficulty, for the stems of most of the gland-tubes, as they lay immediately below the vascular crypt-layer, were, in many of these vertical sections, obliquely or transversely divided, and consequently their precise mode of termination and the position of their mouths could not be followed out (*c*, fig. 4). But in other sections, where the stem of the gland-tube lay perpendicularly to the plane of the surface, and where the knife had passed through its long axis, a short length could be seen going to the deeper surface of the crypt-layer, and inclining indeed directly to the bottom of one of the deeper funnel-shaped crypts, with the cavity of which its lumen was continuous (*d*, fig. 4).

From the examination of surface views of the mucous membrane, more especially when the vessels were injected, I was able to obtain also satisfactory evidence that the glands opened into the deeper part of the funnel-shaped crypts. For, on looking into these crypts through a binocular microscope, I not unfrequently saw that the deeper end possessed an opening which communicated with the stem of a tubular gland. The direction of this opening was in most cases oblique, so that the tube of the gland, immediately prior to its termination, lay with its long axis oblique or almost parallel to the bottom of the crypt, and consequently was transversely or obliquely divided in many of the vertical sections (fig. 4, *c*, *d*). The relation of the orifice of the gland to the bottom of the crypt closely resembled the appearance figured many years ago by Dr SHARPEY in the pregnant uterus of the bitch.* Additional evidence of the communication of the glands with these deeper crypts was obtained in some of the specimens by observing a little plug, formed in all probability either of epithelial cells or of the coagulated secretion of the gland, projecting from the mouth of the gland into the bottom of the cavity of the crypt (fig. 10, *a*).

Owing to the great complexity of the free surface of the uterine mucous membrane from the multitude of crypts, it was not possible to say how many gland tubes opened in a given area. It was evident, however, that they were not so closely set together, but that several smaller cup-shaped crypts (fig. 4, *e*), which did not receive glands, intervened between the deeper funnel-shaped crypts with which the glands communicated. And it was also clear that the number of what I have termed the stems of the gland tubes, which reached the crypt layer, was very much smaller than that of the tubes in the deeper portions of the gland-layer, so that the number of branches springing from each stem must have been considerable.

The glands were lined by a very distinct cylindrical epithelium, which was

* Dr BALY's Translation of MÜLLER's Physiology, p. 1576, figure 212.

Dr SHARPEY, to whom I showed my preparations during the meeting of the British Association in Edinburgh in August of the present year, told me that in the uterus of a pregnant *Manis*, which he had examined some years ago, he found an arrangement of the uterine glands almost identical with that seen in this *Orca*, and that, like myself, he had experienced a difficulty in tracing the glands into the crypts.

closely arranged around the wall of each tube, but leaving a distinct lumen in the axis of the gland. The epithelial cells exhibited no appearance of degeneration, and the glands had the aspect of secreting organs in a state of complete functional activity. I may mention here that in the pregnant uterus of a pig, the fœtus in which weighed only 12 grains, which was examined at the same time, the glands had only half the diameter of those observed in this *Orca*.

The mucous membrane, which formed the walls of the crypts, and in which the glands were imbedded, consisted of a delicate connective tissue containing numerous nucleated corpuscles (fig. 4, *f*). These corpuscles were in part the spindle-shaped nucleated corpuscles of the wall of the capillaries, but more frequently were proper to the tissue itself. In the connective tissue of the gland-layer these corpuscles mostly had the fusiform shape, but in the walls of the crypts a distinct layer of globular or ellipsoidal nucleated corpuscles was seen immediately within the boundary line of the mucous membrane, which was not unfrequently elevated in a gently wavy line immediately superficial to the corpuscles. From their position these cells may be called the sub-epithelial cells of the mucous membrane of the crypts (fig. 4, *g*). In thin sections, more especially where the capillaries were partially filled with the red injection, they could be readily distinguished from the spindle-shaped corpuscles of the capillary wall by the difference in shape, and by the same test there was no fear of confounding them with the epithelial lining of the crypts to be next described.

In many of the sections I was able to trace without difficulty the epithelial lining of the crypts, and obtained the clearest views of the cells in the injected portions of the mucous membrane (fig. 11, *a*). This lining, where it had not been disturbed, was in contact with, and closely followed, the various irregularities of, the mucous surface; but in many places it had been either partially or altogether removed, so that it is obviously readily shed from the membrane. The cells of which it was composed had the appearance of a pavement epithelium, though they were not larger than the broad, free ends of the cylindrical epithelium lining the glands, with which, indeed, the epithelial lining of the crypts was anatomically continuous. I examined, but failed to detect any difference in shape between the cells lining the gland-crypts and those which lined the crypts into which the utricular glands did not open.

The close relation which exists between the uterine glands and the deeper funnel-shaped crypts, and the manifest continuity of the epithelial lining of the one with that of the other, seems naturally to justify the inference, that in the pregnant cetacean, all the crypts into which the glands open are merely the mouths of the glands "somewhat enlarged and widened," and thus to establish a correspondence with the arrangement which Dr SHARPEY first pointed out in the pregnant bitch. The extent to which, if we assume the accuracy of this inference, the dilatation of their mouths may have proceeded, I am not as yet

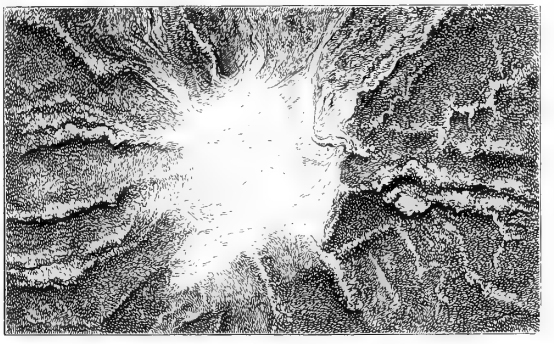
in a position to say, neither do I know if a general enlargement of each gland occurs, as I have had no opportunity of comparing them with the glands in the unimpregnated uterus of the same species of whale; but it is probable that, in the cetacea, as in the other mammals in which they have been seen, the glands undergo a marked increase in size during gestation.

The uterine mucous membrane was very vascular. Numerous small arteries ran through it, either obliquely or in a slightly tortuous manner, to the superficial crypt layer; immediately beneath which they subdivided into terminal branches, which ended in a close compact capillary network, distributed on the sides and at the bottom of the crypts, and immediately beneath the free surface of those bands of mucous membrane which separated the trenches or pits into which the crypts opened from each other (fig. 10). In the elongated bands which lay between the trench-like recesses, the capillaries formed an elongated network. I frequently saw a terminal artery pass up one side of a crypt and give origin to capillaries which arched in a series of festoons around the walls of the crypts; in many cases a distinct capillary ring surrounded the somewhat constricted mouth of a crypt (fig. 12, *a*). The capillaries in the walls of all the crypts belonging to the same group formed a continuous network, which freely anastomosed across the intermediate portions of mucous membrane with the capillaries in the walls of adjacent groups of crypts, so that a continuous capillary plexus was produced, which gave to the free surface of the injected portions of mucous membrane a bright carmine-tinted appearance. In the relative number of the vessels, and the closeness of the network, this plexus may fitly be compared with the capillary plexus of the lungs.

As the small arteries passed through the gland-layer, they gave off branches which ended in a capillary network situated in the connective tissue between and surrounding the tubular glands. Where the stems of the gland tubes reached the funnel-shaped crypts, there the capillaries of the crypts became continuous with those which surrounded the glands. Owing to the open character of the capillary plexus in relation to the glands, there was a strongly marked difference between the vascularity of the crypt-layer and the gland-layer; for the vascularity of the latter was not greater than, and may fairly be compared with, the capillary plexus surrounding the tubular glands of the human stomach. The principal vessels of the gland-layer, like the glands themselves, lay parallel to the general plane of the mucous surface.

The Fœtal Membranes.—The chorion was prolonged from the left into the right horn across the corpus uteri, and extended on each side as far as the opening of the Fallopian tube. The left subdivision, like the corresponding uterine horn, was about twice the size of the right, and contained the embryo. Near the tip of the right horn the chorion was thrown into permanent rugæ, which corresponded in direction to the folds of the uterine mucous membrane,

and fitted into the intervals between those folds. They gradually subsided towards the corpus uteri. In the left horn the rugæ of the chorion were much less strongly marked in correspondence with the feebler folds of the mucous membrane. Except in three limited areas, the entire outer surface of the chorion was thickly studded with villi. These spots, bare of villi, corresponded to the three openings into the uterus, viz., the os uteri internum, and the mouths of the two Fallopian tubes (fig. 13, *a*, *b*, *b*). The spot opposite the os internum had a stellate



Stellate non-villous portion of the chorion of *Orca* opposite the os uteri. About half the size of nature.

form; the central space of which was nearly the size of a crown piece, and from it about twelve radii extended for a short but varying distance. The radii were separated from each other by folds of the chorion, thickly studded with villi, which fitted between the folds of mucous membrane, already described as converging to the os uteri internum.* The spots opposite the mouths of the Fallopian tubes formed the poles of the chorion, and were not larger than kidney beans. They were not very readily recognised, on account of the puckered rugose condition of the polar portions of the chorion, and it was not until after the blood-vessels of the villi had been injected with coloured gelatine that their form and appearance were satisfactorily determined. The absence of villi on those parts of the chorion, which corresponded to the uterine openings, bears obviously a special relation to the absence of a mucous surface at those spots into the depressions in which the villi could be received; for though the chorion was lying loose in the uterine cavity when I opened into it, there can be no doubt that, before the uterine liquor had been evacuated by Mr Gatherer, the chorionic villi had been lodged within the uterine crypts, as the hand and fingers fit into a glove.

* When I described and figured (Transactions of this Society, vol. xxvi., fig. 17) the only bare spot which I had recognised in the chorion of the fœtus of the Longniddry *Balænoptera*, I regarded it, in all probability, as one of the poles of the chorion, as the non-villous spot opposite the os internum was not then known. The further knowledge which I have gained from the examination of this *Orca* leads me now to think, from its size and the projection of the marginal fold, that it was a portion of the bare spot opposite the os uteri internum.

The villi could be seen with the naked eye, but their form and general arrangement were more distinctly recognised when examined with low magnifying powers. Considerable variety was displayed in the arrangement of the villi, in their length, and in the number present in a given area. In many places they were set in rows, so as to form parallel series of ridgelets. In other places they were collected into little tufts, irregular in form and size, which sometimes consisted of two, three, or four villi, but frequently of a much larger number. Solitary villi were also met with, and in the irregular intervals of comparatively smooth membrane, which lay between the bases of the tufts or ridgelets, it was not uncommon, as ESCHRICHT had also observed in his *Phocæna*, to see shorter stunted simple villi projecting from the general plane of the chorion. It is evident that the crypts on the uterine surface, into which the stunted simple villi had been inserted, must have opened directly on its free mucous surface, and not into a trench or pit. As a rule the villi were compound in form, and subdivided into three or more secondary club-shaped villi. The compound villus not unfrequently swelled out at the free summit into a branching crown, which, to adopt ESCHRICHT'S expression, formed a miniature representation of the head of a cauliflower.

The chorionic villi were composed of a delicate connective tissue, in which numerous spheroidal and fusiform nucleated corpuscles were imbedded. Some of these corpuscles were situated in the walls of the finer blood-vessels, but others were proper to the tissue itself. A layer of spherical or ovoid corpuscles was situated immediately within the free surface both of the simple villi and of the secondary portions of each compound villus, and not unfrequently the limitary membrane of the villus was slightly elevated immediately above the individual corpuscles, so that the outline of the villus had a gently undulating appearance. From their position these cells may conveniently be termed the sub-epithelial corpuscles of the villus (fig. 6, *a*). The chorionic membrane between the bases of the villi consisted also of a delicate connective tissue, containing both spheroidal and fusiform nucleated corpuscles. The fusiform cells possessed in many cases very elongated poles, and had distinctly granular protoplasmic contents. Besides those connected with the coats of the finer blood-vessels, others were situated in the membrane itself. The spheroidal corpuscles were proportionally fewer than in the tissue of the villi. No epithelial covering was recognised on the chorionic villi, though it was carefully looked for, but it is very probable that the epithelium had been shed, or rubbed off from their surfaces, before I reached this stage of the examination. For not only had several days elapsed after the death of the animal, but the chorion had soaked for some time in warm water during the process of injection.

When the chorion was cut into, along that surface which was adapted to the convex aspect of the left uterine horn, the umbilical cord, allantois, amnion,

and contained fœtus could be examined. The chorion itself was seen to be distinctly divided into two layers; the outer villous, already described, and an inner thin translucent membrane. These layers were attached to each other by very delicate connective tissue, and between them, the chorionic arteries and veins, passing to and from the villi, ramified.

As the chorion showed no trace of putrefaction, I decided to make an injection of the umbilical vessels and, with the skilful co-operation of my assistant, Mr STIRLING, have succeeded in obtaining some beautiful preparations in illustration of the vascularity of the fœtal membranes.*

The umbilical cord, 15 inches long, consisted of two arteries, two veins, and the pedicle of the allantois (urachus), which were held together by an areolated connective tissue, and were invested by the amnion (Plate XVII. fig. 7, *a*, and Plate XVIII. fig. 15). A careful search was made in the substance of the cord for the umbilical vesicle, or its pedicle, and for the vessels of the vitellus, but without any positive result; for although some elongated threads, which could be isolated from the surrounding tissue, were met with, yet their impervious condition prevented one from concluding with any certainty that they were the remains either of the vitelline duct or of its accompanying blood-vessels.

The two umbilical veins resulted from the bifurcation at the umbilical aperture of the single intra-abdominal vein. They were of large size, and placed at the sides of the cord; and the urachus, with the two umbilical arteries, was situated between them. Sixteen inches from the abdomen of the fœtus the cord bifurcated into a right and left branch, an artery and vein passing off on each side, conducted by the allantois, and situated between that membrane and the amnion, to the chorion. In their course the artery wound around the vein in a spiral manner from left to right on the one side, from right to left on the other. Ten inches from the angle of divergence the vessels reached the chorion, along the line of attachment of the allantois to that membrane, and in their course gave off several branches. As soon as they reached the chorion, the branches of the vein diverged from the corresponding arteries, each pursuing an independent course, and ramifying in an arborescent manner between the two layers of the chorion. The general mode of branching was dichotomous, but occasionally, and this more especially with the arteries, collateral branches arose, in which case two not unfrequently came off close together, and extended for some distance side by side before they proceeded to their respective areas of distribution. Several anastomoses were observed between the branches of the larger veins, and the finer branches of the arteries were occasionally observed to inosculate with each other.

The mode of origin of the terminal arteries varied with the arrangement of

* These and the other preparations obtained from this uterus are preserved in the Anatomical Museum of the University of Edinburgh.

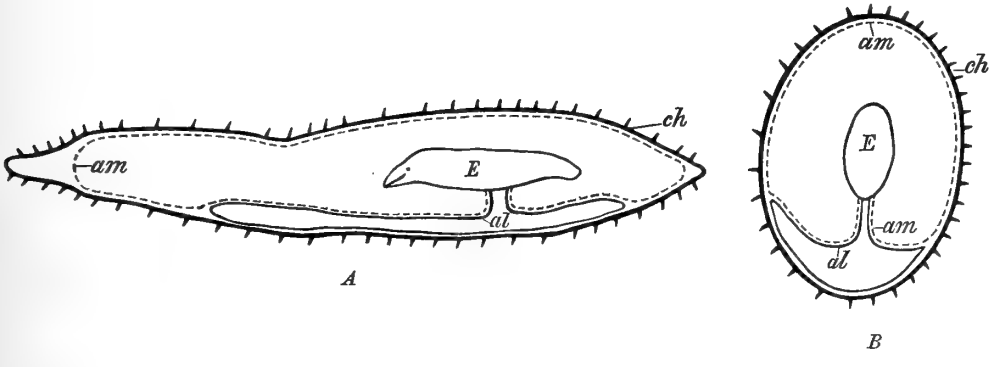
the villi. When these structures were in rows, or scattered, the terminal branches which entered the villi arose independently; but, when the villi were in clusters, several terminal twigs arose close together as from an axis. The arteries did not, like the branches from which they arose, lie parallel to the surface of the chorion, but immediately after their origin entered the villi at the base of attachment, and in the case of a compound villus divided, within its substance, into twigs for the secondary villi. These twigs ascended towards the tip of the villus, and ended in a very compact capillary plexus, situated beneath the free surface of the villus, and in close relation to the sub-epithelial layer of spheroidal cells already described. This plexus may conveniently be termed the intra-villous capillary network (fig. 14, *a*). From the intra-villous plexus capillaries proceeded, which passed out of the villus at its base, and at once joined a capillary network situated immediately beneath the general plane of the chorion. This plexus may be termed, from its position, the sub-chorionic or extra-villous capillary network (fig. 14, *b*). The extra-villous plexus was much less compact than that within the villi; its meshes were, as a rule, elongated. but occasionally more irregular in form. Numerous minute veins arose directly from it, which joined together to form the rootlets of the umbilical vein.

Occasionally I saw a vessel, which was somewhat larger than the capillaries in its immediate neighbourhood, and might therefore be regarded as a direct rootlet of an umbilical vein arising within, and leaving a villus at its base; but this was quite exceptional, for repeated examinations have satisfied me that the arrangement which most commonly prevailed was for the capillaries of the intra-villous plexus to be directly continuous with those of the sub-chorionic network, and for the latter to give origin to an umbilical vein. Hence the blood in its passage from the terminal twigs of the umbilical artery to the rootlets of the umbilical vein has to flow through a complicated capillary system, one subdivision of which lies within the villi, the other beneath the chorionic membrane which connects them at their bases. When the chorion lay in its proper position within the uterus, the first subdivision would have been in relation to the maternal system of capillaries lining the walls of the crypts, the other to the capillaries situated immediately beneath the free surface of those parts of the mucous membrane which separated the trenches or pits into which the crypts opened from each other. This greatly diffused capillary area has undoubtedly a special relation to the comparatively simple mode of union between the maternal and fœtal surfaces in the diffused form of placenta.

The three bare spots on the chorion were almost entirely destitute of blood-vessels, and, after the chorion was injected, contrasted strongly with the surrounding highly vascular villous portion.*

* It may not be out of place to state that some portions of the chorion were injected with a blue-coloured gelatine from branches of the umbilical artery only, when the intra-villous plexus was readily

The urachus freely communicated at its abdominal end with the bladder. At the angle, where the umbilical vessels diverged from each other, the urachus rapidly expanded into a huge funnel-shaped sac-like allantois, capable of holding several pints of fluid. When the allantois reached the chorion, it became prolonged both to the right and left in the form of a comparatively wide, almost cylindrical sac-like horn (fig. 7, *b*, *b*). The left horn-like prolongation extended to 7 inches from the end of the left horn of the chorion, where it formed a cul-de-sac. The right horn-like prolongation entered the right cornu, but did not reach to within 21 inches of the tip of the right horn of the chorion. By far the greater part of the attached surface of the allantois was in contact with the amnion. But, at the points where the umbilical vessels reached the chorion, opposite to the abdominal aspect of the fœtus, the allantois came in contact with the deeper layer of that membrane, to which it continued to be attached by a limited portion of its surface, as far as the ends of its horn-like prolongations. The free surface of the allantois was perfectly smooth, and was bathed by the allantoic fluid.



Explanation of Diagrams.—Outline diagrams to show the arrangement of the membranes at the stage of development described in the text. *A*, Longitudinal section. *B*, Transverse section. *E*, Embryo. *ch*, Chorion. *al*, Allantois. *am*, Amnion represented in a dotted line. The umbilical vesicle is not shown.

The amnion formed a continuous bag from one horn of the chorion to the other, but was not co-equal with it in extent. For though in the left horn it reached to 2 inches from the pole of the chorion, in the right the chorion extended 9 inches beyond the closed end of the amnion (fig. 13 *c*, *c*). Where the amnion was in relation to the dorsal aspect of the fœtus, it was connected by a delicate filamentous tissue to the inner layer of the chorion; but, where the allantois was attached to the chorion, *i.e.*, opposite the abdominal aspect, the amnion was reflected on to the outer surface of the cylindrical horns and funnel-shaped sac of the allantois, and was conducted by that membrane to the umbilical cord, which it invested. Beyond the closed ends of the

filled; that others were injected with a carmine-coloured gelatine from branches of the umbilical vein only, when both the extra and intra-villous capillaries were readily filled; and that others again were injected both from artery and vein, until the coloured gelatines intermingled in the capillaries, and produced there a purple tint.

amnion the chorion formed the sole constituent of the fœtal membranes. Not only was the amnion surrounding the cord abundantly studded with yellowish brown or olive-tinted bodies, smaller even than mustard seeds, but they were also thickly congregated on the amnion where it covered the funnel-shaped sac and horns of the allantois, though they were much more sparingly distributed on that part of the amnion which was in contact with the chorion (fig. 7, *d*). In the right cornu they were absent on that portion of the amnion which extended beyond the horn of the allantois, but on the left side they extended further, and one was seen almost at the closed end of the amnion (fig. 7, *d'*). By the presence of these corpuscles in connection with the amnion, and their absence on the free surface of the allantois, these two membranes were at once readily distinguished from each other. Some of these corpuscles were pedunculated, others sessile, and they had obviously been developed in relation to the attached, and not to the free surface of the amnion, for each was invested by a prolongation of that membrane (as the spleen is invested by the peritoneum), and, where the corpuscles were pedunculated, the pedicle of attachment, which sometimes was $\frac{1}{8}$th of an inch long, was formed by a slender filamentous process of the amnion. Thin sections of the corpuscles, examined with a magnifying power of 480 diameters, were found to be composed of cells, closely packed together, some of which were oval, others somewhat elongated, others somewhat polygonal in shape. In many of the cells clusters of brown pigment granules were contained (fig. 8).

The amnion and allantois were connected together by a very delicate filamentous tissue, in which a few tortuous slender branches of the umbilical arteries and veins were distributed, and frequently formed well-marked anastomosing loops. When the amnion and allantois were separated from each other, these vessels remained in contact with the deep surface of the former membrane. By dissecting off the amnion from the cord, numerous vasa vasorum could be seen distributed to the coats of the umbilical vessels and the urachus.

I also found between the amnion and allantois, close to the trunks of the umbilical vessels which passed to the left horn, three peculiar-looking bodies, the blood-vessels of which were injected from the above-mentioned amniotic arteries. The largest, tri-radiate in form, was $\frac{3}{4}$ inch long by $\frac{1}{2}$ inch in greatest breadth, the others were much smaller, and of an ovoid form. They lay in linear series, the highest and largest was $1\frac{1}{4}$ from the second, and that again $\frac{1}{2}$ an inch from the third. They were connected together by intermediate vessels, and resembled in appearance a chain of small lymphatic glands. When the allantois and amnion were separated from each other, these bodies remained attached to the amnion. When a section was made into one of these bodies, a brown pultaceous mass, contained within a cavity, the wall of which was formed of a fibrous capsule, was exposed. The brown mass, examined microscopically,

was seen to consist of cells, the great majority of which were circular in form, and had a yellowish colour. The smallest of these cells were of the size of lymph-corpuscles, but as a rule they were twice as large. Most of the cells contained a single nucleus, but some possessed two or more, and in a few instances large brood cells were observed, packed full of nuclei, or young cells. Some patches of small hexagonal cells, fitted together by their margins, like the cells of the choroid coat of the eyeball, were also seen; and it is possible that these cells formed a pavement epithelium for the cavity in which the brown pultaceous mass was contained. (Fig. 9, Plate XVII.) These bodies, like the amniotic corpuscles already described, were developed in relation to the attached surface of the amnion, but, unlike the majority of the latter, had not projected so as to assume a pedunculated appearance. In all probability they and the amniotic corpuscles have common morphological relations, though what their function may be it is not easy to determine.

Position and Form of the Fœtus.—The fœtus, a male, enveloped in its membranes, occupied the left uterine cornu. It lay with its beak directed towards the corpus uteri and os internum. The caudal end was curved forward under the abdomen, so that the flanges of the tail were in close relation to the penis (Plate XVIII. fig. 16). The curve of the back of the fœtus corresponded with the convex anterior surface of the uterine cornu. In its position in utero, therefore, it closely corresponded with that of a fœtus of *Globiceps*, figured by Van Beneden,* and it bears out the opinion entertained by that naturalist, that the fœtus in the cetacea is born with the beak foremost. The fœtus possessed the external characters of the genus *Orca*. The beak was not so pointed as in *Delphinus*, or so truncated as in *Globio-cephalus;* the falciform dorsal fin lay in the same transverse plane as the umbilical cord; the pectoral fins were broadly ovoid, flattened on the surfaces, with a rounded anterior and sharp convex posterior border. The colour was dark-slate on the dorsum of the head, back, tail, and upper part of the sides of the body. A distinct pale patch extended horizontally backwards immediately above and beyond the eye slit. The under surface of the lower jaw, throat, and the entire ventral surface to a little beyond the anus, were also pale, and a patch continuous with the ventral surface commenced in front of the penis and extended upwards and backwards along the side of the body. The under surface of the tail was also pale. In the adult these pale patches and surfaces are white, which, contrasting strongly with the otherwise dark colour of the skin, give to the animal a characteristic black and white piebald appearance. But in the fœtus, from the comparative thinness of the cuticle over those surfaces where it was devoid of pigment, the pale patches, instead of being white, were salmon-tinted, owing to the colour of the vascular cutis being transmitted through the

* Bulletins de l'Acad. Royale de Belgique, 2d Series, xx. No. 12.

comparatively thin cuticle. Parallel to and immediately below the base of the dorsal fin, the dark-slate colour was modified by a lighter pinkish-tinted patch, which corresponded with the purplish spot represented by SCHLEGEL in the adult *Orca* which he has figured.* The fœtus measured from the tip of the upper jaw along the middle of the back to the mesial notch of the tail 36 inches. Its greatest girth midway between the root of the flipper and the attachment of the umbilical cord was $18\frac{1}{2}$ inches. From the attachment of the cord to the root of the penis, 3·5 inches; from the latter to the anus, 2·0 inches; and from the anus to the mesial notch of the tail, 10·3 inches. From the tip of the lower jaw to the umbilical cord, 15·2 inches. Length of pectoral fin, 4·8 inches; length of base of falciform fatty fin, 3·2; height measured along anterior border, 4·2 inches. From posterior rise of dorsal fin to mesial notch of tail, 14·2 inches. Between tips of tail lobes along their posterior concave borders, 7·5 inches.

Comparison of Placentation with that of other Mammals.†—I shall endeavour, in making this comparison, to show, as far as the materials at my disposal will permit, the features of resemblance and dissimilarity, not only as regards the general arrangement of the fœtal membranes and uterine mucous surface, but their more minute structure.

The dissection of this *Orca* confirms the results previously arrived at from the dissection of various specimens of the genus *Delphinus*, by the anatomists quoted in my introductory observations, that in the cetacea the chorion extends into both uterine horns, and its surface is so studded with villi as to form a placenta of the "diffused" type, in which, from the absence, so far as was ascertained, of a uterine decidua intermingled with the chorionic villi, the fœtal and maternal surfaces readily separate from each other. It also agrees with the specimen examined by Professor ROLLESTON, in the presence of a bare spot, free from villi, at each of the poles of the chorion. But I have also demonstrated, what had previously been overlooked, that a third, larger, non-villous area is situated opposite the os uteri internum.

Of the mammals, the placentation of which most commonly comes under observation, the sow and the mare also offer well-known examples of the diffused form of placenta. Of these the uniparous mare presents more points of resemblance to the uniparous cetacean than does the pluriparous sow. For in the mare not only does the chorion of the solitary embryo extend from one uterine cornu to the other, and possess small non-villous spots at the poles, but an even larger, stellate, bare spot also exists in relation to the os internum.‡

* Abhandlungen aus dem Gebiete der Zoologie und vergleichenden Anatomie. Part ii. fig. 7.

† October 1871. This section and the final one, entitled "Physiological Conclusions," have been re-written since the Memoir was read.

‡ In one specimen, I observed that the non-villous pole of the horn of the chorion which contained a fœtal foal about 2 feet long, was somewhat smaller than that of the *Orca*, but the bare spot in the

In the pluriparous sow, again, though the poles of the ovum are smooth and almost non-vascular, the third bare spot is not present, for the membranes surrounding each embryo are confined to a single horn, and do not pass across the corpus uteri.* In the sow also the folds of the chorion and uterine mucous membrane do not, as in the whale and mare, lie in the direction of the long axis of the uterine cornu, but at right angles to it.

The bare spots at the poles of the greatly elongated chorion of the cetacean are undoubtedly homologous with the smooth ends of the shorter ellipsoidal chorion of the carnivora, but the non-villous portion is absolutely and relatively much smaller in the former than in the latter. As the carnivora are, as a rule, pluriparous, the conditions necessary for the formation of a third bare spot are non-existent in them, just as is the case in the pig.

But the closer affinity of the mare than of the sow to the cetacean, in the characters of the chorion, is shown also in the arrangement of the villi, and in the distribution of the capillary blood-vessels. The villi of the chorion of the mare are thickly distributed over its surface. They are for the most part compound and arranged in tufts; though isolated simple villi are scattered in the intervals between the tufts. The tufts are, as a rule, somewhat larger than those in the cetacean, and they have more of a brush-like form than of that of the head of a cauliflower, a difference which I find to be due to the secondary villi being elongated and filamentous rather than club-shaped. Not only is a rich capillary network situated within the villi, but this plexus, as I have satisfied myself, from the examination of an injected chorion, freely communicates, as in the whale, with an abundant extra-villous sub-chorionic plexus, from which the rootlets of the umbilical vein arise, so that in both animals a diffused capillary area is produced by similar modes of distribution.

Von Baer and Eschricht long ago pointed out that in the pig the transverse folds of the chorion are notched at the free margin, and the teeth, by growing, become converted into villi. These villi are smaller than in the mare and whale, and at an early period of development can scarcely be said to be present. In a gravid uterus which I examined, where the embryos were 1·3 inch long,

opposite horn was considerably larger, being $2\frac{1}{2}$ inches long by from $\frac{1}{2}$ to $\frac{3}{4}$ inch broad, and with radiated bare processes passing off from its two ends. The bare spot opposite the os internum was twice as large as in the cetacean, and had several strongly-marked, radiating, non-villous processes. The presence of these bare spaces, or at least their exact position and signification in the chorion of the mare, seems to have escaped the notice of veterinary anatomists. Neither Chauveau nor Gurlt make any mention of them in their well-known treatises, and Franck ("Handbuch der Anatomie der Hausthiere," Stuttgart, 1871), whose work is the most recent and fullest in detail of any which I have been able to consult, merely says, "in one or other horn roundish spaces are found, where the villi are sparse and feeble, and here the chorion has a semi-transparent appearance."

* In one pig's uterus, I found that the membranes belonging to the embryo, situated lowest down in the left horn, actually did pass across the corpus uteri into the right horn, but this of course was not the case with the other ova.

multitudes of elongated feeble ridgelets traversed the surface of the chorion, which fitted into corresponding shallow elongated depressions in the uterine mucous membrane, but no true villi were recognised, and the smooth and feebly vascular poles were absolutely and relatively larger than in the cetacean. A distinct and compact capillary plexus, which was injected with carmine and gelatine, was seen both in the ridgelets and in the intermediate portions of the chorion. This plexus was elongated within the ridgelets, and had the same direction, but in the intermediate membrane it formed a polygonal network, so that the entire surface of the chorion, except at the poles, possessed a diffused capillary vascularity, without any differentiation into intra- and extra-villous areas of distribution.

In possessing a basis substance of delicate connective tissue, in which numerous nucleated corpuscles lie, the chorionic villi in the cetacean agreed with the structure of villi generally. The layer of corpuscles situated immediately within the periphery of the villus, which I have described as its sub-epithelial corpuscles (p. 479), obviously corresponds in position, arrangement, and shape, to the corpuscles figured and described as the internal cells of the villus,* by Professor Goodsir in the villi of the human chorion. In a recently published and very elaborate memoir on the "Structure and Function of the Placenta," Professor Ercolani of Bologna has also figured,† in connection with the human villi, a layer of spheroidal corpuscles, which he terms the cells of the internal epithelial layer, situated to all appearance within the villus close to the fœtal vessel, for he represents a layer of membrane immediately outside the cells. His drawing certainly gives one the impression that these cells corresponded in position with the sub-epithelial corpuscles above referred to, but in his text he speaks of them as not included in the thickness of the membrane, but as cells of the decidua serotina which enter into the formation of a new glandular organ which envelopes the villus. Moreover, he regards them as identical with the single layer of flattened spheroidal cells which Dr Farre‡ observed and described as forming the sheath or outer case of the villus, and which undoubtedly belonged to the decidua serotina, and not to the chorionic villi. Although, for the reasons already stated, I did not detect an epithelial layer on the free surface of the villi, yet it is probable that not only they, but the whole outer surface of the chorion, possessed an epithelial covering, as is the case with the chorion in other mammals.

Passing now to the consideration of the characters of the uterine mucous

* Anatomical and Pathological Observations, p. 54, plate 2, fig. 19, f. 1845, reproduced in Anatomical Memoirs, vol. ii. p. 18. Edinburgh, 1868.

† Mémoire sur les glandes utriculaires de l'uterus, et sur l'organe glandulaire de neo-formation, &c. I know this work, which was published at Bologna in 1868, only in the French Translation by Bruch and Andreini. Algier, 1869. Plate X. fig. 2, *b*.

‡ Cyclop. of Anat. and Phys., article *Uterus*, p. 718, fig. 485.

membrane, our attention should especially be directed to the appearance presented by its free surface, to the arrangement of the proper utricular glands, and to the discussion of the question, whether the villi of the chorion in the placental area do, or do not, enter within the mouths of the glands.

Eschricht had recognised that the free surface of the uterine mucous membrane in the gravid porpoise, which he dissected, appeared "cellulosa vel cribrosa." The form of the "cells" was "valde irregularis. Interdum quadratæ vel triangulares sunt, interdum rotundatæ, sæpius oblongæ unum punctum elevatum irregulariter radiatim circumstantes"—a description which closely applies to the depressions termed recesses, trenches, and pits, which I have figured on p. 474 in the gravid *Orca*. It does not very clearly appear, from his description, whether he had recognised the small cup-shaped pouches or pockets opening into or leading out of these larger depressions, which I have named the crypts; so that I am inclined to think that Eschricht's term "cells" must be taken as equivalent to my pits, recesses, or trenches, rather than to my crypts. His account of the arrangement of the closely-packed, branching, uterine glands, applies, in most particulars, equally well to what I have seen in the *Orca;* but from the statement, "ostia areolis seu maculis lævibus insunt, quibus nullæ omnino insident cellulæ," he seems to think that the glands open on the surface of the mucous membrane, not in the "cells" in which the chorionic villi are lodged, but in separate shallow areolæ; and he goes on to say, that for so great a multitude of gland ramifications, there are not more openings on the surface of the mucous coat than in the pig, and the openings are separated by intervals of one or two lines.

In the gravid uterus of a mare, where the fœtus was about two feet long, which I examined several years ago, I observed that the inner surface of its mucous membrane was pitted with minute depressions, for the reception of the villi of the chorion; but unfortunately I omitted to notice the relation which they bore to the uterine glands. In another uterus, in the sixth month of gestation, the free surface of the membrane was crowded with multitudes of crypts, not unlike those described in *Orca*. Opening sometimes within these crypts, but at others on the ridges which separated different groups of crypts from each other, were oval, or almost circular, orifices surrounded by a capillary ring, which were evidently the mouths of utricular glands. In vertical sections the glands were distinctly seen. In the deeper part, branched, tortuous, and with diverticular off-shoots, but in their course to the crypt-layer they ascended almost straight and vertically, so that they could be followed without difficulty, and contrasted strongly, therefore, in this respect with the arrangement seen in *Orca*. The crypt-layer was, as in the cetacean, much more highly vascular than the gland-layer of the mucous membrane, but the vessels ascended to the crypt-

layer parallel to the tubes of the gland.* Both FABRICIUS and VON BAER had previously recognised small openings on the surface of the uterine mucous membrane of the mare into which the villi of the chorion entered, but Professor GURLT† was the first to affirm that the villi passed in this animal into the mouths of the glands. ERCOLANI describes numerous simple gland follicles, lined by a pavement epithelium, as receiving in the mare the chorionic villi. But he considers these follicles to be newly formed during pregnancy, and to be entirely independent of the uterine glands, which, lined by their cylindrical epithelium, and of uniform diameter, open by separate orifices on the uterine mucous surface, and do not receive the villi of the chorion.

In the pregnant sow the surface of the uterine mucous membrane is modified in accordance with the conformation of the corresponding aspect of the chorion, as already referred to. Instead of presenting multitudes of crypts, such as have been described in the whale, the surface is traversed by transverse folds separated by intermediate furrows and fossæ, so as to present an undulating appearance. Shallow depressions, or areolæ, which are to be regarded either as the dilated mouths of the glands, or, as depressions into which the glands open, are scattered over the surface. In an uterus which I examined, where the fœtal pig weighed 12 oz., about twelve of these areolæ, corresponding to the mouths of an equal number of glands, were situated on a portion of mucous membrane $\frac{4}{10}$ths of an inch square. The vessels of this specimen had been injected with vermilion, and the preparation corresponded in appearance to the specimens described by ESCHRICHT, that in injected uteri the areolæ are easily observed, as they are much less vascular than the surrounding portions of mucous membrane.‡ According to VON BAER and ESCHRICHT, little circular or star-like vascular elevations of the surface of the chorion are attached to these dilated orifices of the glands.

In another pig's uterus, where the fœtus weighed only 12 grains, the mouths of the glands could be distinctly seen opening sometimes directly, at others obliquely, and these openings were either on the plane surface of the mucous membrane, or in shallow depressions, and not unfrequently plugs of epithelium were seen projecting through the orifices, exactly in the manner I have described in the pregnant *Orca;* and the gland tube, as in that animal, did not pass vertically to the plane of the mucous surface, but lay obliquely or parallel to it. The intervals between the mouths of adjacent glands were so great that, examined with a $\frac{1}{2}$-inch objective, one, or at the most two, could only be seen at the same time in the field of the microscope; and the intermediate portions of the mucous

* This specimen was injected in 1853 by that excellent anatomist, the late Mr JOHN BARLOW of Edinburgh.

† Handb. der vergleich. Anat. der Haus Säugethiere, p. 431. Berlin, 1860.

‡ This diminished vascularity, as it seems to be, is probably due merely to the vessels being less perfectly filled with the vermilion injection.

membrane between the gland mouths presented an undulating appearance, from the fossæ and furrows, with their intervening ridgelets, which it possessed. The vessels in this specimen were very perfectly filled with a carmine and gelatine injection, and the capillaries were seen to form a close polygonal network, which was quite as abundant around the mouths of the glands as in the intermediate parts of the membrane.

The study of this specimen has been of great service as a guide in determining the signification of the appearances presented by the free surface of the more complicated uterine mucous membrane in the gravid *Orca*. In both animals it was clear that the utricular glands opened on the free surface of the mucous membrane; only, in the *Orca* they opened at the bottom of deep funnel-shaped crypts, but in the pig, either on the plane surface or in shallow fossæ. In both, the gland mouths were separated by intermediate portions of mucous membrane, which in the *Orca* was folded with so much complexity as to form numerous cup-shaped crypts, but in the pig to produce only shallow fossæ and furrows. In both animals the mucous membrane was highly vascular, not only where the glands opened, but in the intermediate portions. In *Orca* the villi of the chorion were lodged both in the crypts into which the glands opened and in the intermediate crypts; in the pig the fossæ and furrows received the highly vascular transverse folds of the chorion, which represented and performed the functions of the villi, and would in course of time have become villous, whilst it is probable that, if the circular or star-like elevations of the chorion had been developed, they would, as Von Baer has shown, have been in relation to the gland orifices. It is clear, therefore, that in the pregnant uteri of these animals, not only the uterine glands, but the intermediate portions of mucous membrane, bear important relations to the chorion.

I have already stated, p. 477, that my observations on the mucous membrane of *Orca* seem to justify the inference, that the deeper funnel-shaped crypts may be regarded as the dilated mouths of the utricular glands which open into them. But, from what I have observed in the mare, it does not appear that in this animal all these glands do necessarily open, or dilate, into crypts at their mouths, for some without doubt presented no such arrangement. I have said nothing as yet, however, of the probable mode of formation of the cup-shaped non-glandular crypts, of which two hypotheses may be advanced in explanation, one to be considered here, but the other to be more appropriately discussed when comparing the cetacean and carnivorous modes of placentation.

It is well known that during pregnancy the uterine mucous membrane not only becomes very vascular, but increases both in superficial area and thickness. Many years ago, John Goodsir pointed out* that the swollen state of

* Op. cit. p. 57. 1845.

the membrane in the human gravid uterus is due, not only, as SHARPEY had shown, to changes in the uterine glands, but to an increase in the amount of the inter-glandular tissue, by the formation of "a texture which consisted entirely of nucleated particles." ERCOLANI had also observed, in the various uteri which he had examined,* this increased growth of the uterine tissue, and in accordance with our present modes of expression, described it as formed by the proliferation of the connective tissue. But he also affirmed that, in all the placental mammals, through the transformation and folding of the uterine mucous membrane in the interspaces between the utricular glands, a new glandular organ is formed, which, however flexuous the mucous membrane may become in different animals, never loses the type of a simple glandular follicle. And further, that it is into the follicles of this new gland-organ that the villi of the chorion penetrate, and not into the utricular glands.

The examination which I have made into the minute structure of the uterine mucous membrane of *Orca* has satisfied me that in it also a great growth of the inter-glandular tissue had taken place, for not only was the connective tissue with its fusiform nucleated corpuscles largely developed, but I distinctly recognised also a layer of sub-epithelial corpuscles, situated close to the surface of the mucous membrane. Epithelial-lined, cup-shaped crypts, for the reception of villi, had formed in great numbers, which had added largely to the superficial area of the membrane. Now, there can be no doubt but that these crypts, which obviously correspond to the simple gland follicles of ERCOLANI, could be formed by a flexuous growth of the mucous membrane, and that the difference presented by this surface in *Orca* and in the pig is simply due to the foldings being more complicated in the former than in the latter—a difference which is in accordance with the greater size and numbers of the villi in the cetacean than in the pachyderm.

In Ruminants, which furnish such characteristic examples of the Cotyledonary placenta, utricular glands can be readily recognised in the uterine mucous membrane. In the gravid uterus of the sheep the mouths of these glands may be seen with the naked eye opening on the plane surface of the membrane in the intervals between the cotyledons, and, when vertical sections are made, there is no difficulty in following them as comparatively straight tubes through its thickness. In the deeper layer of the membrane they branch and bear a strong resemblance to the utricular glands figured by FRANCK in the cow and goat. They ascend also for some distance on the sides of the cotyledons, but their relations to the centre and summits of each of these bodies, and to the openings which admit the chorionic villi, are difficult to determine. Professor SPIEGELBERG, however, maintains that the tubes which open on the sur-

* He gives no description of the cetacean placenta.

face of a cotyledon for the reception of the chorionic villi are only remarkable dilatations of the uterine glands.*

In the zone-like placenta of the Carnivora, the observations of Dr SHARPEY,† which WEBER and BISCHOFF‡ have confirmed, have shown that two kinds of glands, simple and compound, open on the mucous surface of the uterus of the bitch.§ After impregnation both kinds of glands dilate into pits, which receive the fœtal villi. The simple undergo a uniform enlargement, whilst only the mouths and adjacent part of the ducts of the tubular glands are dilated into pits. JASSINSKY even states,‖ that in the bitch all the chorionic villi, without exception, pass into the uterine glands, so that a double membrana propria and a double epithelial covering may be recognised in connection with each villus, one membrane and one epithelial layer belonging to the villus itself, the others to the gland in which it is included.

And here I may refer to the other hypothesis, to which I alluded on p. 491, in explanation of the mode of production of the crypts¶ in the cetacean. It may be that in the *Orca* also both kinds of glands exist, and undergo dilatation during pregnancy, so that the crypts of my vascular crypt layer may include both the uniformly enlarged, short, simple glands and the dilated mouths of the utricular glands. In the absence, however, of any knowledge of the existence of the simple glands in the unimpregnated uterus of the cetacean, the hypothesis previously advanced is to be preferred; as we do know that a great growth of the inter-glandular connective tissue and increase in the superficial area of the uterus take place, which, if thrown into folds, would produce such a crypt-like structure as has been described, without the necessity of assuming the pre-existence and subsequent enlargement of the short simple glands.

In the mammals which possess the Discoid form of placenta LEYDIG** has observed the existence of utricular glands in the mole. Of the Rodents which

* HENLE and PFEUFER's Zeitschrift, vol. xxi.

† Op. cit., p. 1576. ‡ Hunde Ei, plate xiv.

§ WEBER, ROLLESTON, and ERCOLANI have pointed out the presence of utricular glands in the cat. I have also seen them in the badger, in which animal they closely resemble the figure and description given by BISCHOFF of these glands in the bitch. ERCOLANI denies the existence of two kinds of glands in the bitch's uterus, and states that only the utricular glands are present. CARL FRIEDLÄNDER has, however, recently made some observations ("Untersuchungen über den Uterus," Leipzig, 1870), which reconcile the opposite statements of SHARPEY and ERCOLANI. For he points out that, whilst in the quiescent condition of the uterus of this animal only the utricular glands are present, in the period of heat, when the mucous membrane is swollen, and its vessels turgid with blood, simple glands are also met with.

‖ VIRCHOW's Archiv, xl. p. 350. 1867.

¶ To prevent misunderstanding I may state that BISCHOFF specially designates the short simple glands of SHARPEY as the mucous crypts, whilst the longer, branching, convoluted glands are the proper utricular glands. In my description of the uterine mucous membrane of *Orca*, I have employed the term crypts to designate all the pouches or pockets which receive the chorionic villi, whether according to the above hypothesis they are the simple glands uniformly enlarged, or the dilated mouths of the utricular glands.

** Histologie des Menschen und der Thiere, p. 517. 1857.

have been more especially examined, viz., the rat, rabbit, hare, and guinea pig, there is a general agreement among observers that proper utricular glands in the form of elongated tubes do not exist, but the mucous membrane is thrown into complex foldings, which possess an appearance long since compared by Reichert to the convolutions of the brain.* Leydig indeed is disposed to regard the spaces between the folds, with their epithelial lining, as equivalent to colossal glands, although they want the tubular form.

In the Human Subject, where the placenta possesses its most concentrated character, utricular glands are present in the uterine mucous membrane. As is well-known, however, these glands are difficult to demonstrate in the quiescent uterus, and only acquire well-marked characters after conception has taken place or during menstruation. They form important constituents of the decidua vera or uterina on the free surface of which their mouths may readily be seen. As the ovum enters the uterus it becomes enclosed within a chamber formed of the decidua ovuli, the inner surface of which chamber is pitted with shallow depressions, which receive the chorionic villi, but there is no satisfactory evidence to show that these pits in the decidua ovuli are the dilated mouths of the uterine glands.

In the area of the decidua serotina where the placenta is developed, various observers have shown that a great production of globular and spindle-like cells takes place, which are intimately intermingled with the chorionic villi. Carl Friedländer has recently pointed out that both the decidua vera and serotina may be divided into two principal layers, an inner cell-layer intermingled with the chorionic villi, and an outer glandular, which latter lies next the muscular coat. The cells of the inner layer are elongated or rounded colossal cells, frequently with many nuclei, and correspond in appearance to those cells which histologists now term giant cells (*Riesenzellen*). Beautiful representations of these cells have been given by Ercolani in Plate X. of his memoir. The glandular layer contains, amidst its corpusculated connective tissue, hollow spaces clothed with an epithelium, the cells of which are partly flattened, partly cylindrical. These spaces Freidländer regards as the modified utricular glands; but he considers that we still need satisfactory proof of the penetration of the villi into these glands.

As yet only one anatomist has recorded, in a sufficiently precise form, distinct observations which seem to show that some at least of the villi of the human chorion enter the utricular glands in the placental area. Jassinsky describes† thick villi (*dicke Zotten*) in the placental region, which differ from the ordinary chorionic villi in having very few or even no lateral branches, and in possessing knob-like dilatations at their free ends. In each thick villus, he says, two structureless membranes and two epithelial layers may be recognised, the inner

* Müller's Archiv, 1848, p. 79.

† *Op. cit.* p. 346.

epithelium is flattened, and with the structureless membrane with which it is in contact belongs to the villus, whilst the outer epithelium is cylindrical, and with its structureless membrane constitutes the utricular gland into which an ordinary vascular villus has entered. Further, he states that all the uterine glands do not contain villi, but that some remain free. The appearance described by JASSINSKY is obviously the same as that represented by Professor GOODSIR in his well-known figure (Plate II. fig. 19). And although that anatomist did not definitely describe the external cells of the villi as the epithelial lining of the utricular glands, yet he stated that they belonged to the decidua, were the remains of the secreting mucous membrane of the uterus, and played the part of secreting cells by separating from the blood of the mother the matter destined for the blood of the fœtus. As regards therefore the morphological position and the function of these cells, JASSINSKY's observations correspond closely with those of GOODSIR, though he employs a somewhat different mode of expression in his description. Similarly the layer of flattened spheroidal cells, which Dr FARRE described as forming the sheath or outer case of the villus, obviously corresponds with the external cells of GOODSIR and the outer epithelium of JASSINSKY, and belongs, therefore, to the decidua serotina, although FARRE does not definitely state that it forms a part of that structure.

ERCOLANI again considers that the cells of the serotina, or cells of the internal epithelial layer, which penetrate between and surround the chorionic villi in the human placenta, constitute a new-formed glandular organ intervening between the villi and the maternal blood spaces or lacunæ, and the cells of which separate from the maternal blood nutritive material to be absorbed by the villi. These cells he considers to be derived from cells, which multiply in great numbers, furnished by the submucous connective tissue of the uterus. Whilst agreeing, therefore, with GOODSIR and JASSINSKY, in considering the cells of the serotina, which surround a villus, to be concerned in an important way in fœtal nutrition, yet he does not, with the one, regard them as the remains of the uterine mucous membrane, or, with the other, as the epithelium of the utricular glands, but as a new production formed after the period of conception.

Hence there is a common understanding not only amongst these, but other investigators, as VAN DER KOLK and PRIESTLEY,* that the villi of the human chorion are invested by cells, which intervene between the vessels within the villi and the maternal blood-vascular system, and which play an important part in fœtal nutrition, though opinions differ as to their mode of origin.

But the development of a decidua serotina in the placental area, and the intimate intermingling of certain of its anatomical constituents, which are shed at the time of separation of the placenta with the chorionic villi, are not confined to man, but are found in all animals which possess either the discoid

* Lectures on Gravid Uterus, p. 83.

or zone-like form of placenta. It is quite unnecessary for me to go into the proofs on which this statement rests, as ample evidence of its accuracy has been already advanced by Professors Eschricht and Rolleston in their valuable memoirs already so frequently referred to. The shedding of the placental portion of the serotina at the time of parturition, has led zoologists to class all those mammals together in which it occurs as caducous or deciduate mammals.

We may now inquire if there are any structures in the *Orca*, and inferentially in the other mammals which possess a "diffused" placenta, at all comparable to the decidua serotina, although it may not be actually shed along with the fœtal membranes.

I have already stated that the cells of the serotina intervene between the villi and the maternal blood-vessels. In the *Orca* we have also seen that although the vessels of the uterine mucous surface are not dilated into sinuses, but preserve the form of ordinary capillaries, yet that they are separated from the epithelial investment of the villi, not only by the epithelial cells lining the crypts, but by the sub-epithelial corpuscles of the mucous membrane. In their anatomical position these layers of cells correspond therefore to the cells of the serotina. We have no evidence at present that these layers are separated at the time when the membranes come away, though I think it very probable if the chorion of a whale or of a mare, investing a fœtus born at the full period of gestation, were carefully examined, that the epithelial lining of the crypts might to some extent at least be found to be shed along with it. But during the period of involution which follows parturition, it is obvious that great changes, either from actual shedding of portions of its substance, or from degeneration and interstitial absorption, must take place in these and the other constituents of the crypt layer before it can be restored to its proper non-gravid condition. The difference between the diffused placenta of a whale and the concentrated placenta in the human subject appears therefore to be not an essential difference in the presence or absence of certain anatomical structures, but rather a difference in arrangement. In the whale the cell structures developed in connection with the uterine mucous membrane, and which occupy the position of the decidua serotina, are diffused over an extensive surface, and possess a simple laminated arrangement, and the maternal blood-vessels do not lose their capillary characters. The chorionic villi, also, are lodged in comparatively shallow crypts, out of which they can be easily enucleated, either with or without the simultaneous shedding of the cell-layers of the crypts. In the human subject, on the other hand, the cell structures of the serotina, developed in connection with the uterine mucous membrane, are concentrated in a limited area, and so intermingled with the chorionic villi, that, when these are separated, the cells of the decidua must necessarily be shed at the same time. The maternal blood-vessels also assume the form and size of sinuses. Further, I believe that these

two forms of placentation, which at the first glance seem, and are indeed usually regarded as, so widely separated, blend with each other through gradational forms which occur in the other mammalia.

Hence, whilst it may be convenient to employ the terms caducous or non-caducous, deciduate or non-deciduate, in zoological classification, as expressing the shedding or non-shedding of distinctly recognisable portions of the uterine surface, along with the fœtal envelopes, they ought not to be regarded as signifying absolute differences in anatomical structure in the two groups of placental mammals.*

Turning now to a comparison of the arrangement of the membranes which lie within the chorion, we find that, although the allantois in the cetacea is elongated towards the two poles of the chorion, yet that it does not reach their extremities as in the mare and ruminants; still less does it pass through and beyond to form those pouch-like sacs, which Von Baer many years ago described in the pig as the *diverticula allantoidis*. Neither do we find that it lines either the whole, or even the larger part of the inner surface of the chorion, as in one or other of these animals, or as in the carnivora; but its chorionic attachments are limited to that aspect of the latter membrane which is opposite the abdominal aspect of the fœtus. In the persistent condition of its allantois it differs moreover from the human subject and the other mammalia in which that membrane disappears at a comparatively early period of gestation.

The amnion in *Orca*, though it does not reach the poles of the chorion, yet preponderates over the allantois, which is just the opposite condition to the arrangement met with in the solipeds, ruminants, and pachyderms. Projecting into the sac of the amnion, though invested by that membrane, are the small corpuscles, "filiform outgrowths, which are undoubtedly homologous with the similarly placed growths in the early ruminant, and in the soliped embryo, as well as with those on the amnion of the Tenrec," as Rolleston has already pointed out. Dr Sharpey also informs me that he has met with a similar set of bodies in connection with the amnion in *Manis*. It is to be observed that these structures are not limited to the part of the amnion which invests the cord, but are distributed irregularly in connection with its entire surface.

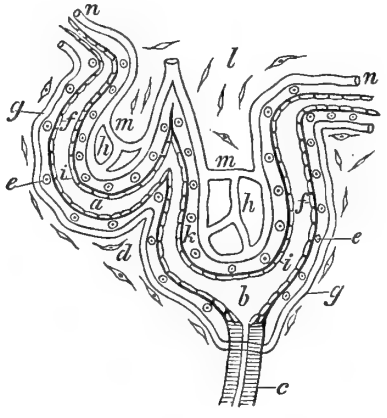
The umbilical vesicle, again, disappears in *Orca* some time before birth, as in the mare, pig, and ruminants, and does not persist in the form of a considerable sac, as in carnivora, rodents, bats, and insectivora; or as a rudiment, as is sometimes seen in the human subject.

In its placental affinities the *Orca*, as will be recognised from the statements made in the comparison I have just instituted, approaches more closely to the

* It is right to state that Professor Huxley, by whom the terms deciduate and non-deciduate were introduced, "by no means intended to suggest that the homologue of the decidua does not exist in the non-deciduate mammals."—*Elements of Comparative Anatomy*. p. 103.

mare than to any other mammal, the placentation of which has been accurately studied. These affinities may be briefly stated as follows:—Both animals are uniparous and possess an elongated chorion, over the entire surface of which, with the exception of three limited areas (two polar and one intermediate), well defined villi are "diffused." In both, the amnion is studded with small corpuscles, and the umbilical vesicle disappears some time before birth. In both, the allantois persists as a large sac, but whilst it preponderates over the amnion in the soliped, it possesses a relatively smaller area in the cetacean. In both, the highly vascular free surface of the uterine mucous membrane is crowded with crypts for the reception of the villi of the chorion, and in both the utricular glands are well developed; but in the mare the glands ascend with a comparatively straight stem almost vertically to the crypt-layer, whilst in the cetacean they are so tortuous as to be followed with considerable difficulty to their termination.*

Physiological Conclusions.—Finally, I may say a few words as to the physiological conclusions to be drawn from the study of the arrangement of the



placental structures found in this *Orca*. And as it may help to give one a clearer insight into this important subject, I shall, in the first instance, briefly summarise and illustrate, by means of the accompanying diagram, the relative position of the constituent elements of the placenta in this animal.

* Although the consideration of the placental affinities of the whale shows it to be more closely allied to the mare than to any other mammal, yet I by no means wish it to be understood that in the other organic systems a correspondence occurs between the cetacean and the soliped closer than can be seen between them and any other class of the mammalia. For in their osteological characters, as Professor Huxley has pointed out, the cetacea are allied to the true carnivora through the extinct Zeuglodon and the Seals; in the possession of a compound stomach and of a third bronchus, they resemble the Ruminants; in the "diffused" character of the chorion, in the presence of a vena azygos (Rolleston), and in the remarkable modifications of the cerebral and intestinal arterial systems, for an account of which I must refer to my memoir on the Longniddry *Balænoptera*, they are allied to the Pachydermata. A full discussion, however, of the relative value of these characters, as determining the zoological position of the cetacea, would be out of place on this occasion.

The placenta is distinctly subdivided into two portions, a maternal and a fœtal. The maternal consists of the specially modified uterine mucous membrane, in which, from the attached to the free surface, the following parts may be recognised :—The utricular glands *c*, imbedded in the connective tissue, and surrounded by an open capillary plexus; and the crypt layer, consisting of *a*, cup-shaped crypts, and *b*, funnel-shaped crypts, into the latter of which the utricular glands *c*. open. In this crypt layer are found the connective tissue (including the fusiform corpuscles *d*, and the layer of spheroidal sub-epithelial corpuscles *e e*) and the close capillary plexus *g g*; the crypts are lined by the epithelial layer *f f*. The fœtal portion consists of the chorion, from which the villi *h h* project and fit into the crypts of the maternal part of the placenta. These villi are invested by the epithelial layer *i i*, and they consist of connective tissue which contains a layer of sub-epithelial corpuscles *k*, of fusiform corpuscles *l*, and a close capillary plexus *m m*, derived from the umbilical arteries, which plexus is continued into an extra-villous chorionic network *n n*, from which the umbilical vein arises. The fœtal and maternal vessels are not in contact, still less continuous, with each other, but are separated by the layer of sub-epithelial corpuscles of the villus, the epithelial investment of the villus, the epithelial lining of the crypt, and the layer of sub-epithelial corpuscles of the crypt. The space between the two epithelial surfaces is intended to show the interval between the fœtal and maternal portions into which the secretion of the uterine glands is poured.

It may be useful to compare the above diagram with the well-known diagrams with which Professors John Reid* and Goodsir have illustrated their views of the structure of the human placenta. By both these anatomists the tufts of fœtal villi were regarded as intimately related to the dilated uterine sinuses, the inner coat of which, or a structure continuous with that inner coat, being reflected on to each tuft. But Goodsir also represented two systems of cells :—The external cells of the villus, belonging to the decidua, which lay in immediate relation to the fœtal aspect of the lining membrane of the maternal sinus; the internal cells which lay within the villus between its vascular loop and its external membrane; and he separated the two systems of cells from each other by a space which he regarded as the cavity of a secreting follicle, of which the external cells were the secreting epithelia.† The human arrangement, as repre-

* Edinburgh Medical and Surgical Journal, January 1841; and Physiological and Anatomical Researches, p. 325. Edinburgh, 1848.

† Although from the description which Professor Goodsir gave of these external cells, he undoubtedly considered them to be of the nature of secreting epithelium, yet he did not represent them in his diagram as situated on the free surface of the maternal placenta, but as separated from the space between the maternal and fœtal portions by a sharp line, as if a membrane intervened. How far he intended this line to represent a definite structure I am unable to say. If such were his intention, then the external cells would rather correspond in position to my layer of sub-epithelial corpuscles of the mucous membrane than to a free epithelium. Similarly his layer of internal cells of the villus corresponds in position, not to the epithelial investment, but to my layer of sub-epithelial corpuscles of the villus.

sented by those anatomists, differs from that in the whale in the sinus-like dilatation of the maternal blood-vessels, and in the much more intimate relation of the tufts of fœtal villi to those sinuses; the closer approximation of the fœtal and maternal vascular systems being effected not only by the projection of the tufts into the uterine sinuses, but by the absence, or at least the non-recognition, of the epithelial investment of the villus. In the whale again, the utricular glands have not, except perhaps at their mouths, lost their tubular character, whilst the space between the two systems of cells in the human placenta, which Goodsir regards as the cavity of a secreting follicle, has, if we conceive it to be formed by a dilated uterine gland, altogether lost its tubular form.

It is generally admitted by physiologists that the placenta is an organ in which a double function is performed—nutritive and respiratory. But there is a difference of opinion as to how far these different functions are carried on by the same structures in this single organ, or how far there may not be separate structures set aside for the performance of each function.

In the early stages of development of the ovum it has indeed been generally admitted that the uterine glands, and the cells of the decidua reflexa and serotina, where such exist, elaborate a material which, when absorbed by the chorionic villi, is engaged in the nutrition of the embryo. But the idea has been also entertained, that, after the new blood-vessels have been developed, both in the villi of the chorion, and in the maternal portion of the placenta, the uterine glands cease to perform their office, and the nutrition of the fœtus is effected by the passage of materials from the blood in the maternal to that in the fœtal blood-vessels. Some have held that the mode of passage consists in the simple transudation of these materials through the walls of the vessels from the maternal to the fœtal vascular systems. Others again have contended,* that two sets of cells intervene between the two systems of vessels, a uterine set (external cells of villus of Goodsir), which selects from the maternal blood, and transmits the selected material into the villus; and a chorionic set (internal cells of villus of Goodsir), which absorbs the material transmitted prior to its passage into the fœtal vascular system.

Ercolani again has advocated a doctrine which, in some important particulars, differs from those of his predecessors. He admits that the utricular glands do furnish materials for the nutrition of the embryo, but only in the early period of its development. And he strives to prove that, from a transformation and greatly increased growth of the uterine mucous membrane, and of the sub-epithelial connective tissue, a new maternal glandular organ is formed, which in its simplest form consists of secreting follicles, arranged side by side and opening on the surface of the mucous membrane. In the human subject,

* See the Memoirs of Professor Goodsir, and Drs Arthur Farre and W. O. Priestley.

he says, the typical form of the glandular organ is wanting, but the cells of the serotina, which invest the chorionic villi, represent the fundamental portions of the gland organ. Into these new-formed secreting follicles, and not into the utricular glands, the villi of the chorion penetrate, and are bathed by the fluid secretion, which they absorb for the nourishment of the fœtus. He believes that these observations completely overthrow the view so frequently entertained that the nutrition of the fœtus is due to an exchange of materials by processes of exosmosis and endosmosis between the two vascular systems.

There can be no doubt that the structures which I have described, both in *Orca* and in the mare, as the crypts of the mucous membrane, are the same as those to which ERCOLANI gives the name of follicles. I have already discussed the probable mode of formation of these structures, and whilst considering that the deeper, funnel-shaped crypts* may, from their relation to the glands, be regarded as their dilated mouths, yet I have inclined to the view that the cup-shaped crypts are pouches formed during gestation by the folding of the surface of the greatly hypertrophied mucous membrane. Hence they may be looked upon as newly-formed follicles; and, so far, I agree with ERCOLANI.

Are they, however, to be regarding as secreting? Here I experience greater difficulty in accepting ERCOLANI'S theory; for although their epithelial lining is anatomically continuous with that of the utricular glands, yet it is not of the same character. Both in *Orca* and in the mare, whilst the glandular epithelium is cylindrical, that lining the crypts is pavement. Now, we are not in the habit of regarding the pavement epithelium as secreting in its functions, for in the localities where it is customarily found, it seems to fulfil merely a protective office, whilst the function of secretion is reserved for cylindrical, spheroidal, or polygonal epithelial cells.

Again, I am not disposed to consider that the utricular glands cease to perform their functions at an early period of embryo-life. In this *Orca*, although the fœtus had reached an advanced stage of development, the vascularity of the glands, their epithelial contents, even the presence of plugs of epithelium or inspissated secretion projecting through their orifices, all gave one the impression of structures in a state of active employment. If this be the case, then the secretion would be poured out into the crypts, and brought in contact with the villi of the chorion. In the mare, however (and it is quite possible also in *Orca*, although I have as yet no positive observations), some of the

* It may be said, as an objection to the inference that the funnel-shaped crypts are the dilated mouths of glands, that in the mare some of the utricular glands open on the surface by circular orifices without exhibiting any dilatation, and that therefore the crypts into which the glands open are, like the other crypts, merely due to a folding of the mucous membrane at that spot. The difference in the character of the epithelial lining of the glands and crypts, and the similarity in the epithelial lining of all the crypts, may also be advanced as additional reasons why all the crypts should be regarded as formed after the same plan, and not by the dilatation of gland orifices.

glands do not open into crypts, and their secretion, consequently, would be brought in contact not with villi, but with the plane surface of the chorion between the bases of the villi.

Now in the diffused form of placenta, and it is probable also in some of the other forms, the villi are not the only absorbing surfaces of the chorion. For whether we regard the process of absorption as conducted through the agency of special cells, or of capillary blood-vessels, both these structures are met with, not only in connection with the villi, but with the plane surface of the chorion between their bases. Hence, it seems to matter little whether the secretion is poured into a crypt or not, as in either case it will meet with a chorionic surface capable of absorption. I am disposed, therefore, to conclude, that in all those forms of placentation in which the utricular glands preserve their structural characters within the placental area they play an important, if not the whole, part in the nutrition of the fœtus, not merely in the early, but throughout the whole period of intra-uterine life.

What office is to be ascribed to the cells which, from their position, I have called the sub-epithelial corpuscles? I am not disposed to think that these corpuscles, either in the chorionic or uterine surfaces, are to be regarded as secreting cells. For in neither case do they lie on the free surface; they are deeper than the epithelium in position, and are located within the delicate connective tissue itself. In form and appearance they resemble those colourless corpuscles to which, from their resemblance to the white corpuscles of the blood or of lymph, the term "lymphoid" is now not unfrequently applied. And it is quite possible that they may have "wandered" out of the adjacent capillaries into the connective tissue. It is probable, therefore, that they may be concerned in the nutrition and growth of this texture, which processes undoubtedly go on with great activity during the period of gestation.

I may now say a few words on the respiratory function of the placenta. No one, I feel sure, could examine the injected preparations of the chorion, and the uterine mucous membrane in *Orca*, without coming to the conclusion that the great vascularity of these structures must have a definite relation to the special functions of the organ. In the mucous membrane a striking contrast was exhibited between the vascularity of the glandular and crypt layers. The former had no greater proportion of vessels than may be found in any gland of the same type, enough to provide for its nutrition and special secretion. The crypt layer, however, had a remarkable vascularity, very much greater indeed than we see in connection with secreting follicles, and the vessels were so arranged as to lie immediately beneath the free surface. The capillary network closely followed the flexuosities of the membrane, and was brought into close relation not only with the villi of the chorion, but with the intermediate portions of that structure. The vascularity of the chorion similarly

was very great, and the capillary network was distributed not only within the villi, but beneath the intermediate portions of the membrane. Hence, two extensively diffused highly vascular surfaces, a maternal and a fœtal, were brought into close apposition with each other, and it is to this arrangement, I believe, that we are to look for the structures concerned in placental respiration.

The conditions, however, under which the interchange of gases takes place, differ very materially in the pulmonic and placental respiratory organs. In the lungs the gases dissolved in the blood have to be interchanged with the air in the air-cells. In the placenta the gases are in a state of solution on the one side, in the fœtal, on the other, in the maternal blood, and the transmission of the dissolved gases would take place through the thin layer of fluid secreted by the utricular glands, which bathes the surface of the chorion. The physical conditions approach therefore more closely to what we find in aquatic rather than in ordinary atmospheric respiration.

EXPLANATION OF PLATES.

Figures 1, 2, 7, 13, and 16, were drawn from nature, under my superintendence, by Mr J. B. Abercrombie; figures 10, 11, 12, 14, and 15, by Millen Coughtrey, M.B.; and figures 3, 4, 5, 6, 8, and 9, by myself.

Plate XVII.

Figure 1. Gravid uterus of *Orca gladiator*, with the cavities opened into, reduced $\frac{1}{14}$th. The single arrow is passed through the corpus uteri from one cornu to the other. The double-headed arrow is passed into the canal of the cervix; *a*, the ovary; *b b*, the Fallopian tubes, of which the right is cut through; *c c*, the round ligaments; *d*, the bladder with the urethra leading from it; *e*, the mouth of the vagina.

Figure 2. A vertical section through the ovary reduced one-half. *a*, the large corpus luteum with its central cicatrix; *b*, the highly vascular body at the hilum.

Figure 3. Cells of the corpus luteum. × 320.

Figure 4. A magnified vertical section through the uterine mucous membrane. *a*, crypt layer; *b*, glandular layer; *c*, transversely divided gland-tubes beneath the crypt-layer; *d*, a funnel-shaped crypt with a gland opening into it, the free ends, and not the sides of the cylindrical epithelium of the glands, were seen in this specimen; *e*, a cup-shaped crypt; *g*, sub-epithelial corpuscles of the crypt.

Figure 5. A magnified view of the utricular glands, with the intermediate connective tissue, as seen in a horizontal section through the glandular layer of the mucous membrane.

Figure 6. A highly magnified view of an uninjected compound villus of the chorion. The secondary club-shaped villi are shown with the corpuscles of their connective tissue. The sub-epithelial corpuscles are indicated at *a*.

Figure 7. A view of the allantois and amnion displayed by everting these membranes, reduced $\frac{1}{12}$th; *a*, the funis; *b b*, the horns of the allantois; *c c*, the horns of the amnion; *d*, the amniotic corpuscles, of which *d'* represents the corpuscle situated near the tip of the left horn of the amnion.

Figure 8. Cell structures from an amniotic corpuscle. × 480 diameters.

Figure 9. Cell structures from one of the peculiar-looking bodies between the allantois and amnion; *a*, cluster of hexagonal cells; *b*, large brood-cell. The cells to the left are sketches of the more usual forms. × 480 diameters.

Plate XVIII.

Figure 10. A magnified surface view of the injected uterine mucous membrane at a part where the furrowed arrangement was well seen. Around the mouths of many of the crypts a vascular ring may be seen, and at the bottom of more than one of the funnel-shaped crypts a plug of epithelium projects, as at *a*, from the mouth of a gland.

Figure 11. A highly magnified view of a uterine crypt obtained in a vertical section through the crypt-layer. The general arrangement of the capillaries is well shown, and the epithelial lining, as at *a a*. An utricular gland, *b*, may be seen passing to the bottom of a crypt.

Figure 12. A magnified vertical section through the wall of the injected uterus; *a*, the crypt-layer; *b*, the gland-layer; *c*, the muscular coat. The relative vascularity of the different parts is shown in the figure.

Figure 13. Chorion reduced $\frac{1}{12}$th; *a*, the large intermediate non-villous spot opposite the os uteri; *b b*, the polar non-villous spots; *c c*, the poles of the right and left horns of the amnion.

Figure 14. A magnified surface view of the injected chorion; *a a*, the intra-villous capillary plexus; *b b*, the extra-villous capillary plexus; *c*, branch of the umbilical artery; *d*, a rootlet of the umbilical vein. In this figure the umbilical arteries and intra-villous capillaries are coloured red, the extra-villous capillaries and umbilical vein black.

Figure 15. A transverse section through the cord reduced $\frac{1}{2}$; *a*, the umbilical arteries; *b b*, the umbilical veins; *u*, the urachus.

Figure 16. Fœtus of *Orca gladiator* reduced $\frac{1}{4}$th.

EXPLANATION OF WOODCUTS.

Page 474. Surface view, under a low power of the microscope, of a portion of the uninjected uterine mucous membrane. The recesses, furrows, and pits into which the pockets or crypts open are darkly shaded in the figure.

Page 479. Stellate non-villous portion of the chorion opposite the os uteri.

Page 483. Outline diagrams to show the arrangement of the membranes at the stage of development described in the text; A, longitudinal section; B, transverse section; E, embryo; *ch.* chorion; *am.* amnion, represented by dotted line; *al.* allantois.

Page 498. Diagram of placenta of Orca—

a. Cup-shaped crypt.
b. Funnel-shaped crypt, with
c. Gland opening into it.
d. Fusiform connective tissue corpuscles of crypt.
e e. Large sub-epithelial corpuscles of same.
f f. Epithelial lining of crypts.
g g. Blood vessels of crypt-layer.
h h. Chorionic villi, with
i i. Their epithelial investment.
k. Sub-epithelial corpuscles of villus, and
l. Fusiform connective tissue corpuscles.
m m. Intra-villous capillaries.
n n. Extra-villous capillaries.

The interspace between the fœtal and maternal portions, in which the letters *a b f* and *i* are placed, is for the sake of distinctness made comparatively wide in this figure.

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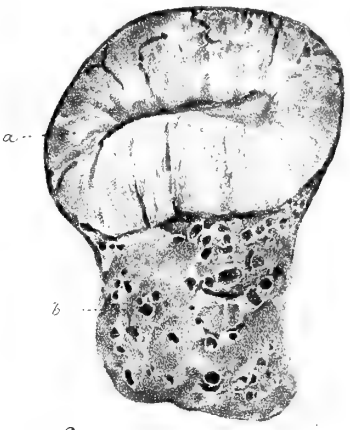

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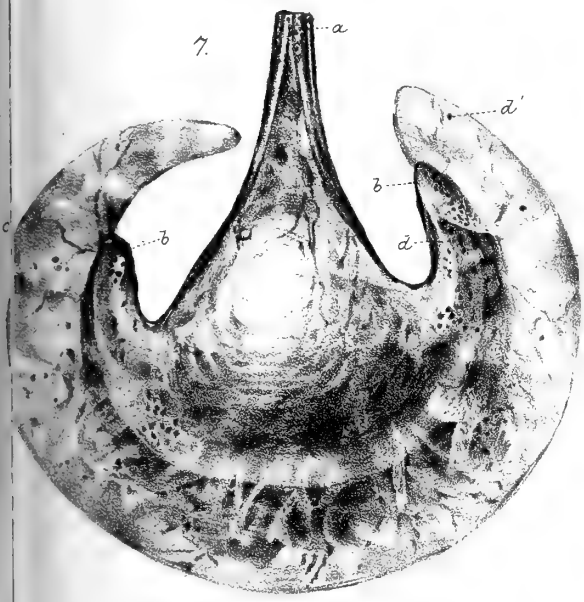

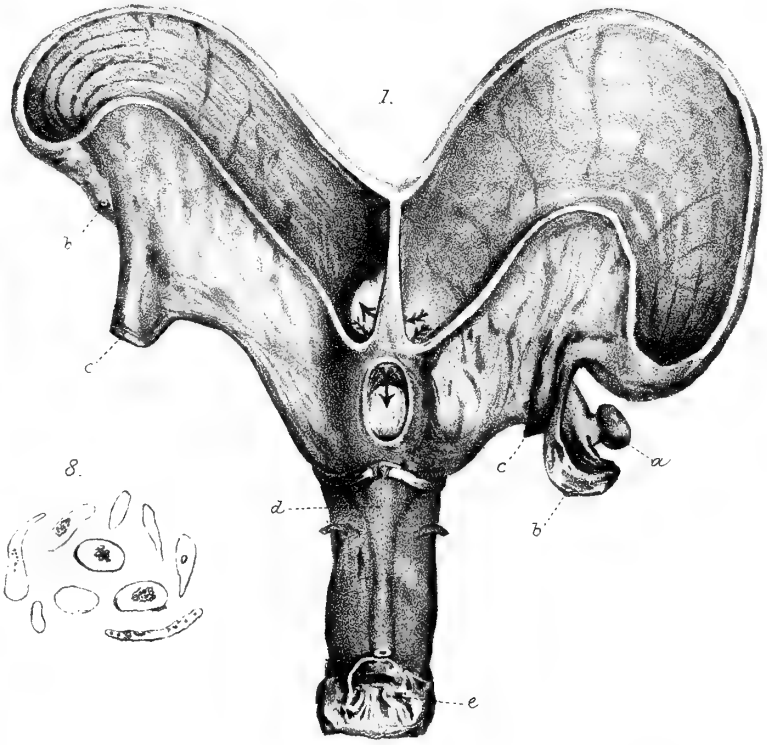

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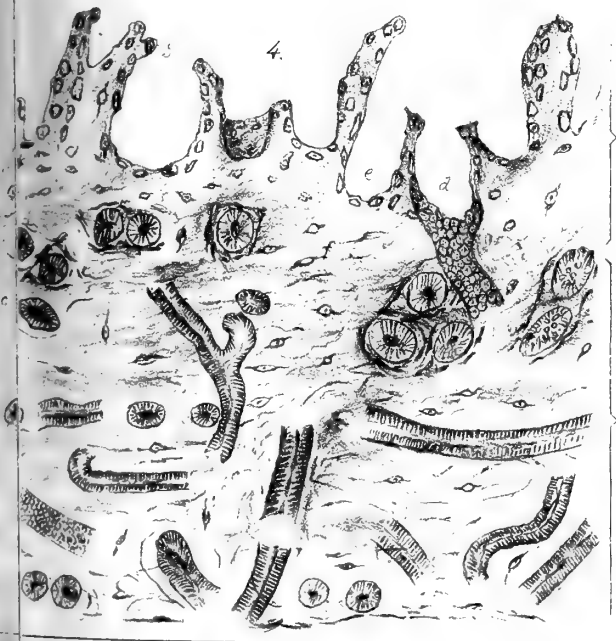

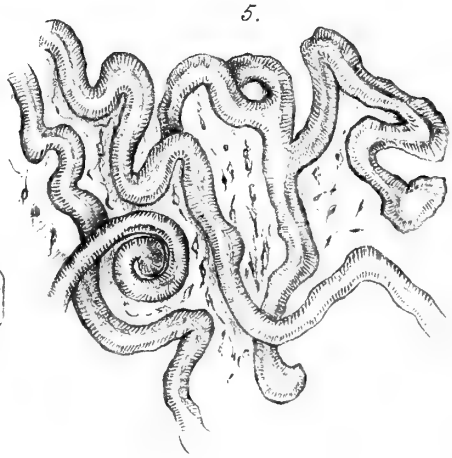

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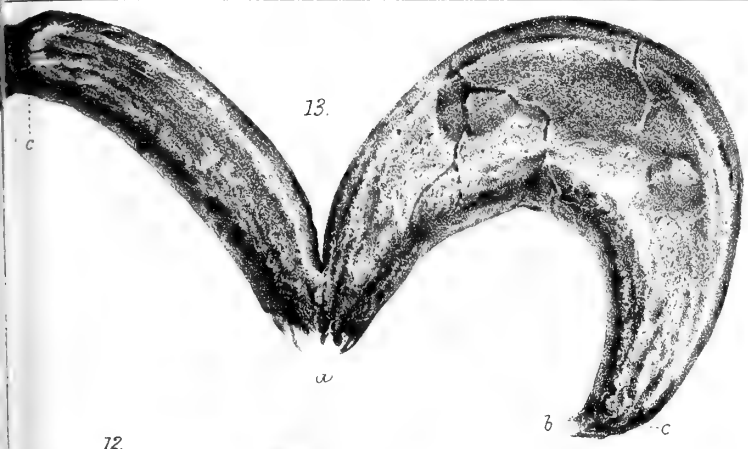
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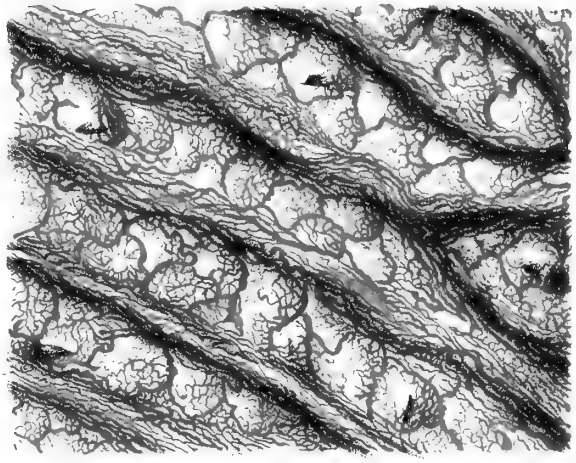
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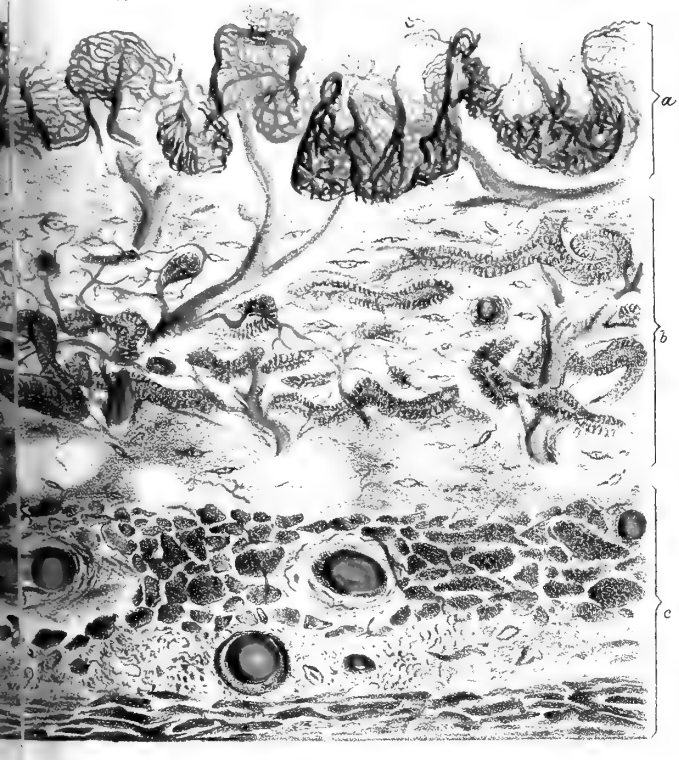
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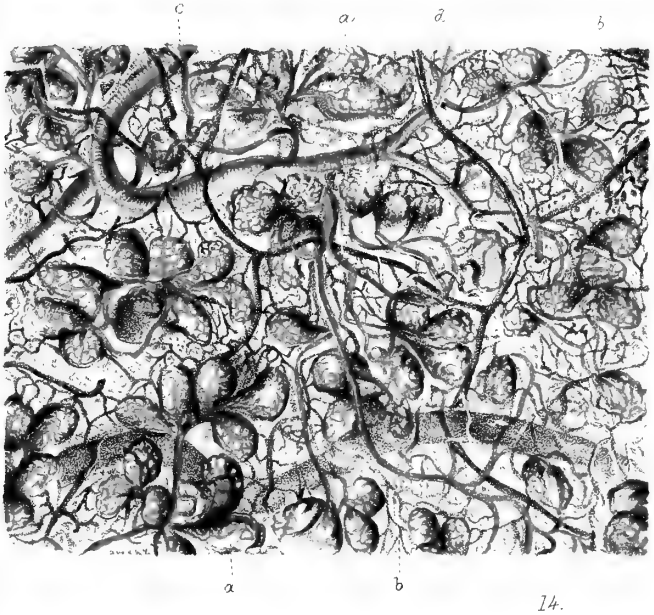
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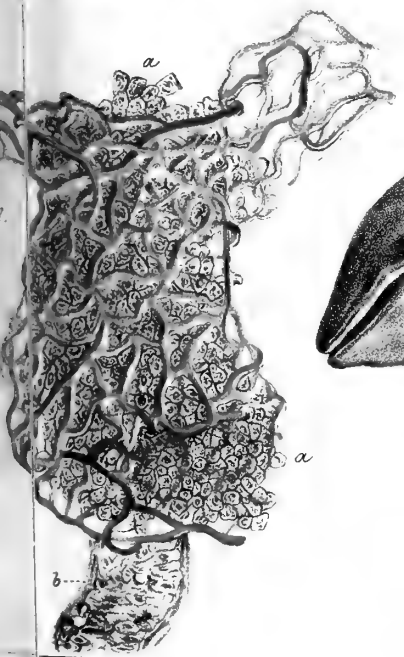
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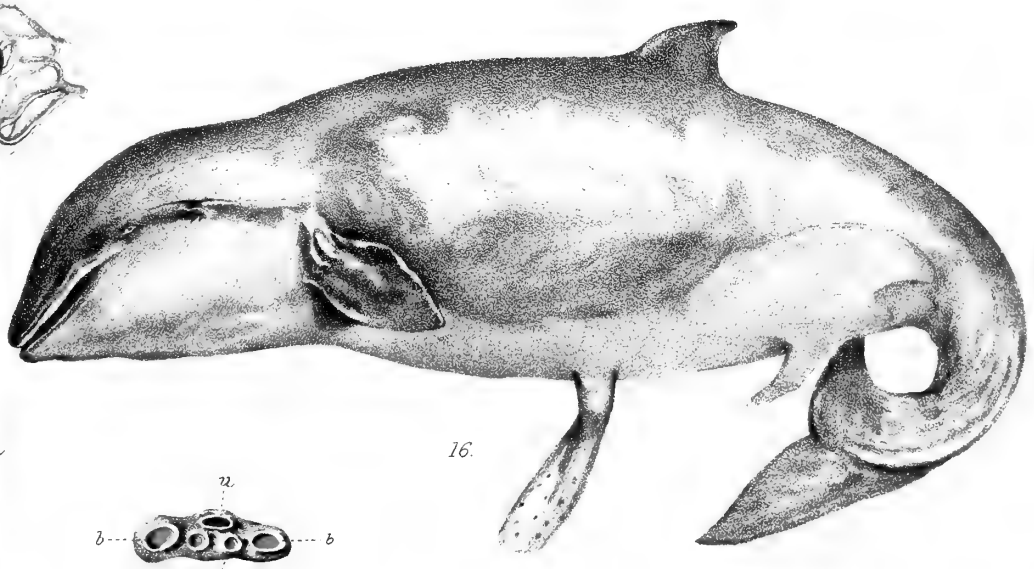
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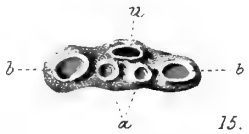
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XIX.—*On some Abnormal Cones of* Pinus Pinaster. By ALEXANDER DICKSON, M.D., Edin. & Dublin.; Regius Professor of Botany in the University of Glasgow. (Plates XIX.–XXII.)

(Paper read 1st May 1871. Given in for publication 23d October 1871.)

It is well known that although the overwhelming majority of specimens of fir cones exhibit one or other of the simple spiral arrangements represented by the terms of the ordinary series $\frac{1}{2}, \frac{1}{3}, \frac{2}{5}, \frac{3}{8}, \frac{5}{13}$, &c., whose generating and successive secondary spirals are indicated by the numbers 1, 2, 3, 5, 8, 13, &c., yet exceptional cases occur now and again, where we find either conjugate spirals of the ordinary system, or arrangements (usually simple, but sometimes conjugate) belonging to other systems of spirals. Of these exceptional arrangements, perhaps the most common are bijugates of the ordinary system, giving the numbers 2, 4, 6, 10, 16, 26, &c., and simple spirals belonging to the system $\frac{1}{3}, \frac{1}{4}, \frac{2}{7}, \frac{3}{11}, \frac{5}{18}$, &c., giving the numbers 1, 3, 4, 7, 11, 18, &c. More rarely, trijugates of the ordinary system occur, giving the numbers 3, 6, 9, 15, 24, 39, &c.; or spirals of the system $\frac{1}{4}, \frac{1}{5}, \frac{2}{9}, \frac{3}{14}, \frac{5}{23}, \frac{8}{37}$, &c., giving the numbers 1, 4, 5, 9, 14, 23, 37, &c.; not to speak of various other arrangements, some of which will fall to be considered in the special cases which form the subject of the present communication.

The occurrence of exceptional arrangements in structures exhibiting so much general uniformity as fir cones, naturally raises the question as to whether these deviations may not be deduced from the simple spiral of the ordinary system, or from some fundamental form, affording a common basis for both.

In his great work on the Arrangement of the Scales on Fir Cones, ALEXANDER BRAUN, in speaking of the occasional occurrence of cones where the most apparent secondary spirals, instead of being, as usual, 5 and 8 in number, are 4 and 7, refers to the temptation to explain away the anomaly by assuming the abortion of the fifth and eighth secondary spirals respectively, only, however, to reject such an assumption as an absurdity of the same kind, as if 2-nary, 4-nary, and 7-nary flowers were considered respectively as 3-nary, 5-nary, and 8-nary ones reduced by abortion; adding, that "it will be better

calmly to pursue the investigation, rejecting all premature hypotheses, which can never be more than substitutes for science."*

In their essay on the arrangement of curviserial leaves, the brothers BRAVAIS approach this question somewhat more closely. In dismissing the idea of abortion in such cases, BRAUN occupied his position mainly, it would appear, in consequence of the absence of any supporting evidence. The celebrated French authors, on the other hand, actually observed, in capitula of *Dipsacus* and in fir cones, certain cases where, in the same inflorescence, there occurred an actual change from one spiral system to another, accompanied by a diminution in the number of secondary spirals. They do not appear, however, to have had a very definite idea as to the exact manner in which this diminution in the number of secondary spirals is effected. Although on the whole they seem inclined to treat the phenomenon in question as the result of abortion of secondary spirals,—as, for example, when referring to certain capitula of *Dipsacus* with 16 and 26 as the numbers of the secondary spirals at the base, suddenly changing to 15 and 26, or 15 and 25, or 16 and 24, they state that here "there is no doubt as to the *abortion* of the missing spirals, since they are as evident as their fellows at the base of the capitulum,"†—yet, in the *résumé* at the end of their essay, considerable uncertainty is indicated in the sentence, that "the *convergence* of two spirals into one is to be explained by partial *abortion* of one of the spirals, or, if preferred, by the *coalescence* of two spirals into one."‡

Of cases of this kind occurring in fir cones, MM. BRAVAIS describe two cones of *Pinus Pinaster* (*Pin maritime*), one where the lower part of the cone exhibited secondary spirals 7 S, 12 D (series $\frac{1}{2}, \frac{2}{5}, \frac{3}{7}, \frac{5}{12}, \frac{8}{19}$, &c.), while towards the apex the arrangement changed to 7 S, 11 D (series $\frac{1}{3}, \frac{1}{4}, \frac{2}{7}, \frac{3}{11}, \frac{5}{18}$, &c.);§ and a second, in which the lower four-fifths of the cone exhibited secondary spirals 9 S, 13 D (series $\frac{1}{4}, \frac{2}{9}, \frac{3}{13}, \frac{5}{22}$, &c.), while at the upper fifth the arrangement changed, by suppression of one of the spirals by 9, to 8 S, 13 D (ordinary series $\frac{1}{2}, \frac{1}{3}, \frac{2}{5}, \frac{3}{8}$, &c.)‖. Such cases, along with some others, chiefly in capitula of *Dipsacus sylvestris*, lead MM. BRAVAIS into a discussion of the general question of the transition from one arrangement to another, involving a change in the number of secondary spirals. As regards their "curviserial" forms,

* BRAUN, Vergleichende Untersuchungen über die Ordnung der Schuppen an den Tannenzapfen; Nova Acta Acad. C.L. xv. 1, p. 316.

† L. et A. BRAVAIS, Sur la disposition des feuilles curviseriées. Ann. des Sc. Nat. 2me sér. vii. p. 100.

‡ *L. c.* pp. 106, 107. § *L. c.* p. 93. ‖ *L. c.* p. 103.

however (under which they include such arrangements as those in fir cones), they are disposed to admit the occurrence only of such transitions as take place by way of "*convergence*" of secondary spirals, resulting in *diminution* of number. For example, after referring to the possible derivation of an arrangement with 5 and 7 secondary spirals (series $\frac{1}{2}, \frac{2}{5}, \frac{3}{7}, \frac{5}{12}$, &c.) from an ordinary one with 5 and 8, by abortion of one of the spirals by 8, and adding that "the series 1, 4, 5, 9 . . . . $\left[\frac{1}{4}, \frac{1}{5}, \frac{2}{9}, \frac{3}{14}, \frac{5}{23}, \text{&c.}\right]$, does not admit of explanation by the way of abortion, and that one can deduce it from the ordinary series only by supposing a *superfœtation*, or addition of a new spiral, among the secondary spirals by 8," they continue, "This hypothesis appears to us altogether improbable, since, in the face of an immense number of instances where two spirals converge into one, we cannot, on the other hand, cite one (apart from rectiserial stems), where one spiral *diverges* into two similar and parallel ones."*

Not having any strong belief in the fundamental distinction between the "curviserial" and "rectiserial" forms of these authors, and knowing that "divergence" or bifurcation of vertical rows (which are, in one sense, to be regarded only as the steepest secondary spirals) is not very rare in "rectiserial" *Cacti* and succulent *Euphorbiæ*, I have not been surprised to encounter, as I have done, cases of "divergence" of secondary spirals in fir cones. In the following remarks, however, I shall treat chiefly of the "*convergence*" of secondary spirals, a phenomenon which, I think, I shall be able to explain more definitely than has hitherto been done; reserving to a future occasion more extended reference to the phenomenon of "*divergence*" of spirals.

For some of the cones to be described, I am indebted to the kindness of R. Smyth, Esq., Emyvale, county Monaghan, Ireland; others I obtained in the woods at Muirhouse (seat of H. Davidson, Esq.), near Edinburgh; further, I am indebted to Professor Balfour for permission to examine the collection of cones in the Museum at the Royal Botanic Garden, Edinburgh, where I found the remarkable cone of *P. lambertiana*, which was lately exhibited before the Society,† and to which I shall recall attention in the following remarks, as also a cone of *P. Pinaster*, with $\frac{5}{22}$ spiral, which was exhibited on the same occasion, and of which I give an outline figure in Plate XX. fig. 8.

I shall, in the first place, give a brief description of the cones forming the subject of the present paper; after which we shall be in a position to judge of and discuss the bearings of the abnormal phenomena.

I. Cone of *P. Pinaster*—Mr Smyth—(Plate XX. figs. 1 and 2; Plate XXI. fig. 1). Length of cone $5\frac{1}{4}$ inches. At the base there is a right-handed $\frac{8}{37}$

* *L. c.* pp. 104, 105.

† See Proceedings R. S. Edin., vii. pp. 398, 399.

spiral (series $\frac{1}{4}, \frac{1}{5}, \frac{2}{9}, \frac{3}{14}, \frac{5}{23}, \frac{8}{37}$, &c.), with secondary spirals 9 S, 14 D, 23 S. A little above the base, however, two of the nine spirals to the left "converge" into one, leaving, from that point up to about the middle of the cone, an arrangement with secondary spirals 8 S, 14 D, 22 S, = a left-handed bijugate of the series $\frac{1}{3}, \frac{1}{4}, \frac{2}{7}, \frac{3}{11}, \frac{5}{18}$, &c., whose two fundamental spirals have each the divergence $\frac{5}{18 \times 2}$. About the middle of the cone, two of the fourteen spirals to the right converge into one, leaving from thence to the top of the cone an arrangement of secondary spirals 8 S, 13 D, 21 S, = a left-handed $\frac{13}{34}$ spiral of the ordinary series $\frac{1}{2}, \frac{1}{3}, \frac{2}{5}, \frac{3}{8}, \frac{5}{13}, \frac{8}{21}, \frac{13}{34}$, &c. The following table (where the three regions are roughly termed "top," "middle," and "bottom") will render the arrangement intelligible:—

TABLE A.*—*Cone of* Pinus Pinaster.

	S	D	S	D	S	D	S	V	
Top,	1	2	3	5	8	13	21	34 =	$\frac{13}{34}$
Middle,	—	—	2	6	8	14	22	36 =	$\frac{5}{18 \times 2}$
Bottom,	—	1	4	5	9	14	23	37 =	$\frac{8}{37}$

II. *P. Pinaster*—Mr SMYTH—(Plate XIX. fig. 1; Plate XX. fig. 3; Plate XXI. fig. 2). Length of cone $5\frac{3}{4}$ inches. From the base to near the top there is a right-handed $\frac{5}{18}$ spiral (series $\frac{1}{3}, \frac{1}{4}, \frac{2}{7}, \frac{3}{11}, \frac{5}{18}$, &c.), with secondary spirals, 4 D, 7 S, 11 D. Near the top of the cone, however, two consecutive scales in one of the spirals by 4 to the right (adjacent scales of two of the spirals by 7 to the left) have partially coalesced, giving beyond that point an arrangement of secondary spirals 4 D, 6 S, 10 D, = a left-handed bijugate of the ordinary series, whose two fundamental spirals have each the divergence $\frac{3}{8 \times 2}$. The following table represents the arrangement:—

TABLE B.—*Cone of* P. Pinaster.

	D	S	D	S	D	V	
Top,	—	2	4	6	10	16 =	$\frac{3}{8 \times 2}$
Bottom,	1	3	4	7	11	18 =	$\frac{5}{18}$

* In this and the following tables, under S, are indicated the numbers of spirals, generating as well as secondary, running to the *left*; under D, the numbers of those running to the *right*; while under V, are indicated the numbers of vertical rows.

III. *P. Pinaster*—Muirhouse—(Plate XX. figs. 4 and 5; Plate XXII. fig. 1). Length of cone $3\frac{1}{3}$ inches. Some scales on one side are somewhat damaged, by having been bitten, apparently before the cone was mature. The lower third of this cone exhibits a left-handed trijugate of the ordinary system, with secondary spirals 6 D, 9 S, 15 D, 24 S, and whose three fundamental spirals have each the divergence $\frac{5}{13 \times 3}$. Two of six spirals to the right "converge" into one, producing in the middle third of the cone the arrangement 5 D, 9 S, 14 D, 23 S, = a right-handed $\frac{8}{37}$ spiral (series $\frac{1}{4}, \frac{1}{5}, \frac{2}{9}, \frac{3}{14}, \frac{5}{23}, \frac{8}{37}$, &c.). In the upper third of the cone, we have two further changes: in the first place, two of the nine spirals to the left "converge" into one, giving the arrangement 5 D, 8 S, 13 D, = a left-handed spiral of the ordinary series, probably $\frac{13}{34}$; and then, a little higher up, two consecutive scales of one of the spirals by 5 to the right (adjacent scales of two of the spirals by 8 to the left) have partially coalesced, almost precisely in the same way as the two scales near the top of the last cone, giving beyond that, up to the top of the cone, the arrangement 5 D, 7 S, 12 D, = a right-handed spiral of the series $\frac{1}{2}, \frac{2}{5}, \frac{3}{7}, \frac{5}{12}, \frac{8}{19}$, &c., probably $\frac{13}{31}$.

The changes in this very complicated cone are shown in the following table:—

TABLE C.—*Cone of* P. Pinaster.

	S	D	S	D	S	D	S	V	
Top,	—	1	2	5	7	12	19	31 =	$\frac{13}{31}$
Below Top,	1	2	3	5	8	13	21	34 =	$\frac{13}{34}$
Middle,	—	1	4	5	9	14	23	37 =	$\frac{8}{37}$
Bottom,	—	—	3	6	9	15	24	39 =	$\frac{5}{13 \times 3}$

IV. *P. Pinaster*—Muirhouse—(Plate XX. figs. 6 and 7; Plate XXII. fig. 2). Length $4\frac{1}{2}$ inches. In this cone, nine secondary spirals to the left run continuously from near the bottom to the top. At the very bottom, there is a considerable amount of irregularity, some of the scales being of exceptional size and shape. It is probable, however, that were it not for the mal-development, the arrangement here would be a $\frac{7}{16}$ spiral, similar to what we meet further up on the same cone. However this may be, a "divergence" distinctly takes place of one secondary spiral into two, which form members of a set of eight running to the right. Thus the first arrangement which we can legitimately

determine in this cone is one with secondary spirals 8 D, 9 S, = a left-handed $\frac{2}{17}$ spiral (series $\frac{1}{8}, \frac{1}{9}, \frac{2}{17}$, &c.). This spiral is continued through between 40 and 50 scales of the cone, when two of the eight secondary spirals to the right converge into one, giving us the arrangement 7 D, 9 S, = a right-handed $\frac{7}{16}$ spiral (series $\frac{1}{2}, \frac{3}{7}, \frac{4}{9}, \frac{7}{16}$, &c.), which, after being continued through between 20 and 30 scales, gives place to a left-handed trijugate of the ordinary series, with divergence $\frac{2}{5 \times 3}$, by two of the spirals by 7 becoming replaced by one of a set by 6. Neglecting the very bottom of the cone, we have the changes represented in the following table :—

TABLE D.—*Cone of* P. Pinaster.

	D	S	D	S	V
Top,	—	3	6	9	$15 = \frac{2}{5 \times 3}$
Middle,	1	2	7	9	$16 = \frac{7}{16}$
Bottom (a little above the)	—	1	8	9	$17 = \frac{2}{17}$

V. *P. Pinaster*—Muirhouse—(Plate XIX. fig. 3). Length of cone $3\frac{1}{3}$ inches. The upper part of this cone exhibits a left-handed $\frac{8}{21}$ (or possibly $\frac{13}{34}$) spiral. Carrying the eye downwards, however, we begin to observe, a little below the middle, rudimentary scales of small size and somewhat peculiar shape, intercalated with considerable regularity among the others, so as to appear as projections placed between the angles of the larger scales. As the base is approached, the scales in the downward continuation of the larger series become gradually reduced in size, till they are practically indistinguishable from the smaller ones; the general arrangement becoming, at the same time, so crowded and confused as to render precise determination of the spiral impossible.

In addition to the above, I would recall attention to the abnormal cone of *Pinus lambertiana* which I exhibited to the Society on a former occasion. This cone is noteworthy, not only as showing a transition by *convergence* from a bijugate of the system $\frac{1}{2}, \frac{2}{5}, \frac{3}{7}, \frac{5}{12}$, &c., giving the numbers 4, 10, 14, &c., to a simple spiral of the system $\frac{1}{4}, \frac{1}{5}, \frac{2}{9}, \frac{3}{14}, \frac{5}{23}$, &c., giving the numbers 1, 4, 5, 9, 14, &c., but also as showing a transition, conversely, by *divergence*, from the latter to the former.

The following table represents the arrangement :—

TABLE E.—*Cone of* Pinus Lambertiana, *in Museum, Edinburgh Botanic Garden.*

	S	D	S	D	S	V	
Top,	1	4	5	9	14	23	$= \frac{5}{23}$
Middle,	—	2	4	10	14	24	$= \frac{5}{12 \times 2}$
Bottom,	1	4	5	9	14	23	$= \frac{5}{23}$

Having submitted the foregoing facts, I shall now proceed to consider :—

1*st*, in what the so-called *convergence* of secondary spirals really consists ;

2*d*, what constitutes affinity of different spiral systems as regards their possible or actual derivation one from another ; and

3*d*, whether it is possible to conceive of the varying spirals in fir cones, or in other plants, being mediately or immediately derived from some one fundamental arrangement in a given set of cases.

1*st*, As to the nature of "convergence" of secondary spirals. It cannot fail to strike the attentive observer that a certain absurdity is involved in the idea of coalescence, or fusion of two secondary spirals into one. Secondary spirals, it is to be remembered, have only a relative existence. For example, in a cone with an $\frac{8}{21}$ spiral the very same scales which constitute the eight secondary spirals running to the one hand, make up the thirteen running to the other. The same objection applies to "convergence" considered as the result of an abortion or suppression of a secondary spiral ; for it is as difficult to conceive of the abortion of one spiral, which has only a relative existence, as of the fusion of two similarly circumstanced. To take a special case. About the middle of Cone III., described above, an ordinary trijugate changes by "convergence" into an $\frac{8}{37}$ spiral; but it would be quite as correct to say that coalescence (or abortion) occurred among the spirals by 15, or by 24, as among those by 6, &c. (see Plate XXII. fig. 1). MM. BRAVAIS appear to have felt this difficulty, but content themselves with arguing for the probability of the abortion occurring among the more apparent secondary spirals, where the successive insertions are in contact, as contrasted with the improbability of its occurrence among the less apparent secondary spirals whose insertions are not contiguous.

Having disposed of the hypotheses of *abortion* and *fusion* of secondary spirals, respectively,—hypotheses which are, in fact, little more than different attempts to express what is simply one of the results of a certain disturbance, viz., diminution in the number of secondary spirals,—we proceed to inquire if there are any facts to guide us in ascertaining the proximate cause of the disturb-

ance itself. To do this we have only to look at the upper portion of Cones II. and III. In each of these a change is ushered in by the partial fusion of two adjacent scales. These scales may be viewed either as consecutive members of one secondary spiral, or as adjacent members of two parallel ones; as, however, their relative position is strictly defined by reference to the spiral in which they are consecutive members, which it cannot be by simple reference to any two parallel spirals in which they occur, the former description is that which must be adopted. In these cases it is impossible to doubt that *it is the coalescence or fusion of two consecutive scales in one of the secondary spirals which leads to or causes the general disturbance of the arrangement.* When such a disturbance takes place, a convergence of certain secondary spirals becomes prominently visible; but this convergence is not at all more real, although more apparent, than the convergence of other secondary spirals whose component members do not happen to be in contact. It will be noted, moreover, that this disturbance affects the numbers of all the secondary spirals, excepting only those among which the fusion of consecutive scales occurs; for example, in Cone II. consecutive scales in one of the spirals by 4 have coalesced, and it is these spirals by 4 alone which run continuously throughout the two systems without diminution in number. That a similar explanation legitimately applies to all cases of "convergence," even where the duplex nature of what I would term the *scale of convergence* is not demonstrable, I think few will be inclined to doubt.

At this point, I may now conveniently refer to the method to be adopted in numbering the scales on the cones exhibiting "convergence." From the circumstance of the "scale of convergence" resulting from the fusion of two adjacent scales which are usually at a considerable interval from each other on the generating or fundamental spiral, it is evident that the disturbance consequent thereon must, at the very least, extend to all the scales which would have been included between the numbers of the two scales which have coalesced, if, indeed, it does not involve a region of the cone extending both above and below the level of the scale of convergence. At first sight it might appear to be the simplest method to consider the scale of convergence as the point of passage from the one system to that succeeding it—as at once the last term of the lower system, and the first of the upper. Here we might reckon the scales in the lower system either up to the lower, or up to the higher, of the two components of the scale of convergence. In either way, however, we should encounter a difficulty; as in the former case a considerable number of scales would escape the reckoning, while in the latter the double enumeration of a considerable number of scales would be involved. The disadvantage of double enumeration also attaches to a method suggested to me by a friend, viz., to number the scales from below the level of the convergence, according to the spiral of the lower system, as far up as one can go above it, and from above

that level, according to the spiral of the upper system, as far down as one can go below it. The method now to be described, and which I have employed in numbering the outline figures of the cones in Plate XX. figs. 1–7, and in the construction of the plans or diagrams of the same in Plates XXI. and XXII., although to a certain extent artificial and arbitrary, yet has the advantage of reducing to a minimum the number of doubtful or ambiguous scales. My procedure is as follows:—The arrangements above and below a given convergence are noted; then, in order to ascertain how the secondary spirals of two such arrangements would most naturally fit or run into one another, constructions of the two arrangements are made in such a way that the last term of the lower system coincides with the first (*i.e.*, No. 0) of the upper; or if either or both of the systems happen to be conjugate, one of the last terms, or of the first, or of each, as the case may be, is to be placed at the common point of the two systems. Further, the constructions are made so that those secondary spirals which correspond in number and direction in the two systems shall be continuous; these spirals being, as above indicated, those among which the fusion of consecutive scales has, or is presumed to have, occurred. To take an example. Supposing we have to join or fit together a $\frac{2}{17}$ spiral below, and a $\frac{7}{16}$ spiral above, as in Plate XXII. fig. 2; a construction is made of the lower spiral, and its last term is taken as the starting-point of the one above, which is thence constructed in such a way that the lines of its secondary spirals by 9 are continuous with the 9 in the arrangement below. The lines of the secondary spirals by 8 in the lower, and of those by 7 in the upper system, are now drawn (these being the lines among which the convergence is most apparent, and which, of course, have approximately the same direction), when the next proceeding is to join the 8 below to the 7 above, which is effected as follows:—the lower extremities of the seven upper lines are joined to the upper extremities of those seven of the eight below, which lie nearest them in the same direction. The upper extremity of the eighth or remaining lower line is then joined to the nearest (in the same direction) of the lower extremities of the seven above, when it becomes apparent that, in the construction, it is this last point which is the point of convergence, and, moreover, that this point corresponds to No. 6 of the upper system. The cone under examination is now taken, and the "scale of convergence" marked as No. 6 of the upper spiral. This upper spiral is now reckoned back to No. 0, up to which point, on the other hand, the scales of the lower spiral are continuously reckoned. When this has been done, it will be found, in the case before us, that *one* scale has been excluded from the enumeration; and, on turning to the construction, it will be seen that this scale occupies a position corresponding to a point where one of the junction

lines between the upper seven and lower eight spirals happens to intersect one of the lines by 9 running continuously through the two systems in the other direction. In the case before us, there is only one such intersection; but, as we shall presently see, there may be two or more such points in similar associations of other spiral systems, which, in the same way, will be found to correspond in position to scales excluded from the enumeration; or, again, there may be no such intersections, in which case every scale in the cone can be included in the continuous enumerations. Again, it will be found that the different transitions differ in the value in the upper system to be attached to the scale of convergence. To illustrate the above, I may refer to the diagrams in Plates XXI. and XXII., with which the outline figures of the corresponding cones on Plate XX. may be compared. In doing so, it will only be necessary for me to indicate the spirals by their systems,—thus, 1, 2, 3, 5, 8, &c., or 1, 3, 4, 7, 11, &c., and so on,—the particular term of its series to which a given spiral belongs being quite immaterial as regards the present question. The unnumbered scales on the outline figures of the cones, and the intersections corresponding thereto in the diagrams, I have marked with asterisks. In Plate XXI. fig. 1, we have the system 1, 4, 5, 9, 14, &c., passing into the bijugate 2, 6, 8, 14, &c., with three intersections corresponding to three unnumbered scales on the cone, and No. 2′ of the upper system as the point or scale of convergence; also, this same bijugate 2, 4, 6, 8, 14, &c., passing into 1, 2, 3, 5, 8, 13, &c., with one unnumbered scale, and No. 6 of the new system as the scale of convergence. In Plate XXI. fig. 2, the system 1, 3, 4, 7, 11, &c., passes into the bijugate 2, 4, 6, 10, &c., with no unnumbered scales, and No. 1′ of the new system as the scale of convergence. In Plate XXII. fig. 1, we have the trijugate 3, 6, 9, &c., passing into 1, 4, 5, 9, &c., with two unnumbered scales, and No. 4 of the new system as the scale of convergence; then 1, 4, 5, 9, &c., passing into 1, 2, 3, 5, 8, &c., with no unnumbered scales, and No. 4 as the scale of convergence; and, lastly, 1, 2, 3, 5, 8, &c., passing into 1, 2, 5, 7, &c., with one unnumbered scale, and No. 3 as the scale of convergence. In Plate XXII. fig. 2, we have 1, 8, 9, 17, &c., passing, as above mentioned, into 1, 2, 7, 9, 16, &c., with one unnumbered scale, and No. 6 as the scale of convergence; and 1, 2, 7, 9, 16, &c., passing into the trijugate 3, 6, 9, 15, &c., with two unnumbered scales, and No. 1 as the scale of convergence.*

With regard to the second point that I proposed to consider,—viz., as to what constitutes *affinity* of different spiral systems as regards their possible or actual derivation one from another; in other words, upon what the aptitude of different spirals to pass into one another depends,—it might, *à priori*, have been

* It might, perhaps, be possible for a mathematician to furnish a formula, whereby, from two spiral systems given, to deduce the number of ambiguous scales, and the value in the upper system of the scale of convergence, thus saving the trouble of a preliminary geometrical construction.

imagined that resemblance in the divergence of the generating spiral would be the bond of union in cases of transition. It is manifest, however, from the instances I have given above, that although in some of the cases we find a close resemblance between the generating divergences of the two spirals between which a passage occurs,—as, for example, between $\frac{13}{34}$ and $\frac{13}{31}$,—yet much more frequently do we find the transition occurring between spirals with widely different generating divergences,—for example, between $\frac{2}{17}$ and $\frac{7}{16}$, or between $\frac{8}{37}$ and $\frac{13}{34}$. Such facts, coupled with the circumstance that in these transitions the direction of the generating spiral is very frequently reversed, and that, not unfrequently, we have a transition from a simple spiral to a conjugate or *vice versâ*, are sufficient to show that the aptitude of spirals of different systems to pass into each other is quite independent of what is ordinarily supposed to be the most essential element of a spiral arrangement, viz., the divergence of the generating spiral. On the other hand, it is to be noted that the correspondence in the numbers of the secondary spirals and verticals is always very close between the spirals which pass into one another; indeed, so much so, that the conclusion seems forced upon us, that here we have the essence of what may be called the *genetic affinity* in such cases, which may be expressed in the following terms:—that, *as regards their production or origination, spirals of different systems are to be considered as allied in proportion to the numerical correspondence of their secondary spirals and verticals.*

I shall now turn to the third and last point to be considered, viz., whether it is possible to conceive of the varying spirals in fir cones, or in other plants, being mediately or immediately derived from some one fundamental arrangement in a given set of cases. This question opens up an interesting, but I am afraid very dangerous, field of speculation. To simplify matters we may confine our attention to a few of the commoner arrangements—arrangements which may be found to prevail over an entire cone. Among such (as I have already indicated at the commencement of this paper) are the simple spirals of the ordinary system; after which the bijugate of the ordinary system and spirals of the system $\frac{1}{3}, \frac{1}{4}, \frac{2}{7}, \frac{3}{11}, \frac{5}{18}$, &c., are conspicuous; and after these the trijugate of the ordinary system and spirals of the system $\frac{1}{4}, \frac{1}{5}, \frac{2}{9}, \frac{3}{14}$, &c., may be mentioned. Have these different forms a common origin? If they have, it is in the highest degree probable that their descent from that common origin is by way of "convergence." Although admitting the occasional occurrence of *divergence* of secondary spirals, yet I am ready to agree with MM. Bravais in considering it as an improbable element in the production or derivation of the commoner forms.

The idea which, perhaps, most naturally occurs is that the simple spiral of the ordinary system is the fundamental form; we may therefore, in the first place, look how the other forms may be derived therefrom.

(*a.*) The ordinary bijugate is derivable from the ordinary simple spiral through the intervention of the system 1, 3, 4, 7, 11, &c., thus,—

1	2	3	5	8	13
	1	3	4	7	11
		2	4	6	10

(*b.*) The system 3, 4, 7, 11, &c., is directly derivable from the ordinary system, thus,—

1	2	3	5	8	13
	1	3	4	7	11*

(*c.*) The ordinary trijugate appears to be derivable from the simple spira of the ordinary system only by way of the bijugate, and hence thus,—

1	2	3	5	8	13
	1	3	4	7	11
		2	4	6	10
			3	6	9

(*d.*) The system 1, 4, 5, 9, 14, is similarly derivable from the ordinary system by way of the bijugate, thus,—

1	2	3	5	8	13	21
	1	3	4	7	11	18
		2	4	6	10	16
		1	4	5	9	14

To the foregoing derivations the most serious objection is, that it seems improbable that the bijugate, which is the commonest of the anomalous forms, should be the result of two convergences; and still more so, that the not very rare trijugate of the ordinary system, and the also not very rare simple system 1, 4, 5, 9, 14, &c., should each be the result of three such transitions.

In the next place, let us take the ordinary bijugate and see how the other systems may be derived from it.

(*a.*) The ordinary simple system is derivable by convergence from the bijugate only, it would seem, by way of the system 1, 4, 5, 9, &c., thus,—

	2	4	6	10
	1	4	5	9
1	2	3	5	8

* It will be remembered that in Cone III. the system 1, 2, 5, 7, 12, &c., is derived from the ordinary system by coalescence of consecutive scales in one of the secondary spirals by 5. Here, the system 1, 3, 4, 7, 11, &c., would be derived from the same by coalescence of consecutive scales in one of the secondary spirals by 3.

This derivation is highly improbable, and, indeed, quite inadmissible; although it is interesting to note that in Cone III. (see diagram in Plate XXII. fig. 1), a spiral $\left[\frac{13}{34}\right]$ of the ordinary system is actually derived from the system 1, 4, 5, 9, &c. Failing this derivation, we may ask if it is possible for the ordinary simple system to be derived from the bijugate by abortion of one-half of the scales? At first sight this derivation seems, and perhaps is, much more improbable than the first one. In the very remarkable cone, however, described above, and figured in Plate XIX. fig. 3, a process of abortion of this kind, arrested half way, seems to have occurred. In looking at the lower part of this cone, it is quite apparent that had the large and small scales been developed equally we should have had a bijugate arrangement. It is just conceivable, however, that these small scales may be the result of a "superfœtation" (to borrow MM. Bravais' very obstetrical term); but this does not seem at all probable. The derivation by abortion would, of course, be represented thus,—

2	4	6	10	16
1	2	3	5	8

(*b*.) The system 1, 3, 4, 7, 11, &c., is derivable from the ordinary bijugate only by way of the simple spiral of the ordinary system, and this may be done by either of the methods indicated under the last head.

(*c*.) The ordinary trijugate, as already indicated, is directly derivable from the bijugate, thus,—

2	4	6	10
	3	6	9

(*d*.) The system 1, 4, 5, 9, &c., is also directly derivable from the bijugate of the ordinary system, thus,—

2	4	6	10
1	4	5	9

In looking at the two foregoing schemes of derivations, it is evident that the great difficulty lies in the absence of any probable derivation, either of the ordinary bijugate from the ordinary simple spiral, or conversely, of the ordinary simple spiral from the bijugate. As to the other systems, it is evident that 1, 3, 4, 7, 11, comes most naturally from the simple ordinary spiral; while the ordinary trijugate and the system 1, 4, 5, 9, 14, are most readily derived from the ordinary bijugate. At one time I was inclined to accept the bijugate as the fundamental form;* but the more I reflect on the matter, the more I am con-

* This view I published (under reserve) in the abstract of this communication in the Society's Proceedings, vol. vii. p. 453.

vinced of the futility of the endeavour to derive the different forms from one origin. Indeed, we seem almost compelled to *recognise both the ordinary simple spiral and the ordinary bijugate as fundamental forms*, i.e., *forms with either of which a cone may commence without the intervention of another*; and if this be done, the derivation of the various systems from the one or from the other would be a very simple matter.

Before concluding, I would submit a tabular analysis of the five flower-spikes of *Banksia occidentalis*, already brought under the notice of the Society, but which may very profitably be reconsidered in connection with the above communication.

Tabular Analysis of five flower-spikes of Banksia occidentalis *in Museum of Economic Botany, Royal Botanic Garden, Edinburgh.*

One, with	—	—	—	7	7	$14 = \frac{1}{2 \times 7}$
Two „	—	—	1	6	7	$13 = \frac{2}{13}$
One „	—	1	2	5	7	$12 = \frac{5}{12}$
One „	1	2	3	5	8	$13 = \frac{5}{13}$

I shall not stop to inquire from what one or more fundamental forms these may be derived, but it is very interesting to note how, among these forms, we have spirals of the most widely different fundamental divergences, closely resembling each other in the number of their secondary spirals and verticals, just as we have seen above in the case of the fir cones.

It is possible that, in ignorance, I have gone over ground which has been trodden before; for example, I have not had access to any of SCHIMPER's works on phyllotaxis. However, as it is in the highest degree improbable that the abnormal forms above described should repeat themselves, I rest assured in the belief that I have contributed at least new, if not valuable matter.

In conclusion, I would specially thank my friend Professor TAIT for the many valuable suggestions I have received from him in the course of this work, and for his patience and readiness in assisting me when in any difficulty.

EXPLANATION OF PLATES XIX., XX., XXI., XXII.

[In Plate XIX. the figures are drawn on stone from photographs.

In Plate XX. the figures are photo-lithographic reductions from outlines made in the following manner:—Photographs of the cones were obtained (the cones having been previously painted of a uniform grey colour), and on these the outlines were carefully gone over with a steel "crow-quill" and Indian ink. This done, the photographs were then *washed out* with a solution of Cyanide of Potassium (about 5 grains to the ounce of water); the outlines drawn remaining, but now, of course, on white paper. These outlines, after being retouched and intensified with Lamp-black, and receiving the addition of the numbers, were then photo-lithographed to the scale required, and colour added by chromo-lithography. I have thought it worth while to record the above process, as it may be found to be very useful in many cases where an accurate outline of a given object is required.

The diagrams in Plates XXI. and XXII. are photo-lithographic reductions from drawings on a larger scale.]

Plate XIX.

Figure 1. Cone II.; about natural size. The two secondary spirals by 7, which converge into one of a double set by 3 at the top, are distinguished by being shaded of a lighter tint than the others. The scale of convergence is obviously double.

Figure 2. Cone III.; somewhat magnified. Here, as in the last case, the scale of convergence near the top of the cone is obviously double.

Figure 3. Cone V.; somewhat magnified. Showing the small scales intercalated among the larger ones towards the lower part of the cone.

Plate XX.

Figures 1 and 2 represent different aspects of Cone I.; considerably reduced. In fig. 1, two secondary spirals by 9, coloured red, are seen to converge into one by 8, which is continued to the top of the cone. In fig. 2, two secondary spirals, coloured blue, in a double set by 7, are seen to converge into one by 13, which is continued to the top of the cone. See diagram in Plate XXI. fig. 1.

Figure 3. Cone II.; considerably reduced. The same view as that in Plate XIX. fig. 1. Two secondary spirals by 7, coloured red, are seen to converge into one of a double set by 3. The scale of convergence is obviously double. See diagram in Plate XXI. fig. 2.

Figures 4 and 5. Different aspects of Cone III.; about naturalsize. Fig. 4 is the same view as that in Plate XIX. fig. 2. Two secondary spirals, coloured blue, in a triple set by 2, converge into one by 5, which is continued to the top of the cone. Of the three secondary spirals by 9, coloured red, the two uppermost converge into one by 8; which last, and the lowermost of the aforesaid three, converge in their turn into one by 7. The last scale of convergence (coloured purple from the blue and red spirals happening to cross) is, like that near the top of Cone II., obviously double. See diagram in Plate XXII. fig. 1.

Figures 6 and 7. Different aspects of Cone IV.; considerably reduced. In fig. 6, two spirals by 8, coloured red, about the middle of the cone, are seen to "diverge" from a single one at the base. In fig. 7, two secondary spirals by 8, coloured red, converge into one by 7; while, higher up, two of the spirals by 7, coloured blue, converge into one of a triple set by 2. See diagram in Plate XXII. fig. 2.

Figure 8. Cone, from Museum of Economic Botany, Royal Botanic Garden, Edinburgh; considerably reduced (natural size $4\frac{1}{3}$ inches). The arrangement in the lower part of this cone is somewhat confused, and has not been determined. From about the middle, however, up to the top, a regular $\frac{5}{2}\frac{5}{2}$ spiral (series $\frac{1}{4}$, $\frac{2}{6}$, $\frac{3}{1}\frac{3}{3}$, $\frac{5}{2}\frac{5}{2}$, &c.) is exhibited. As has been pointed out by MM. Bravais, this system is readily derivable by convergence from the system 1, 4, 5, 9, 14, &c.

Figure 9. Cone, from Mr Smyth, Emyvale; considerably reduced (natural size $4\frac{1}{2}$ inches). This cone exhibits a very regular spiral of the series $\frac{1}{4}$, $\frac{1}{6}$, $\frac{2}{9}$, $\frac{3}{14}$, &c. It will be seen that the lines by 37 are scarcely vertical, so that the spiral has probably the divergence $\frac{13}{60}$.

[Plates XXI. and XXII. The diagrams or plans here hardly require explanation. The regions exhibiting the different spiral arrangements are marked off from each other by horizontal lines projecting laterally at the level where each new system commences; the arrangement in each region being indicated by a fraction alongside of it. I have marked the "scales of convergence" with their number in the upper of the two systems in the respective cases; adding, within brackets, the numbers of the actual or presumed components of these scales according to the spiral of the lower system,—the actual without, the presumed with, a mark of query.]

Plate XXI.

Figure 1. Diagram of Cone I. It will be noted that here, in order to save room, the uppermost spiral is carried up only to No. 36 of the 106 or 107 scales in the corresponding region of the cone.

Figure 2. Diagram of Cone II.

Plate XXII.

Figure 1. Diagram of Cone III.

Figure 2. Diagram of Cone IV.

FIG. 3.

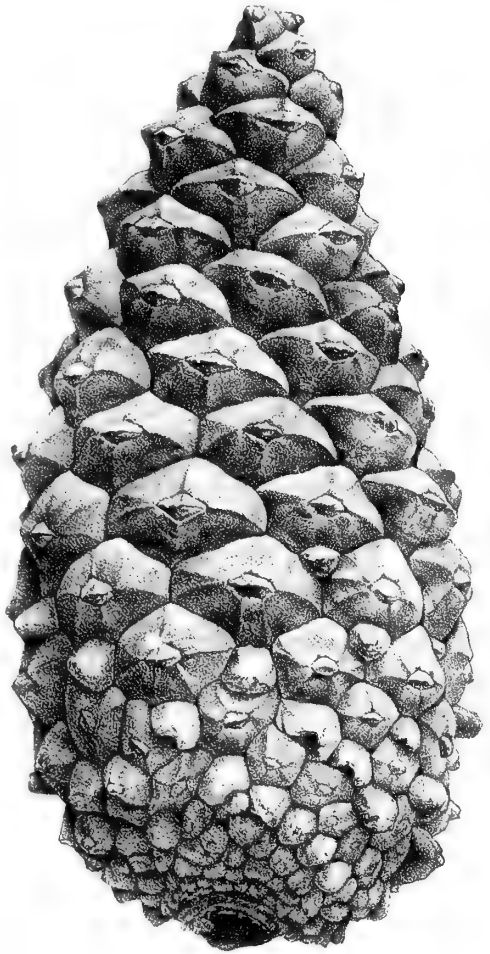


FIG. 2.

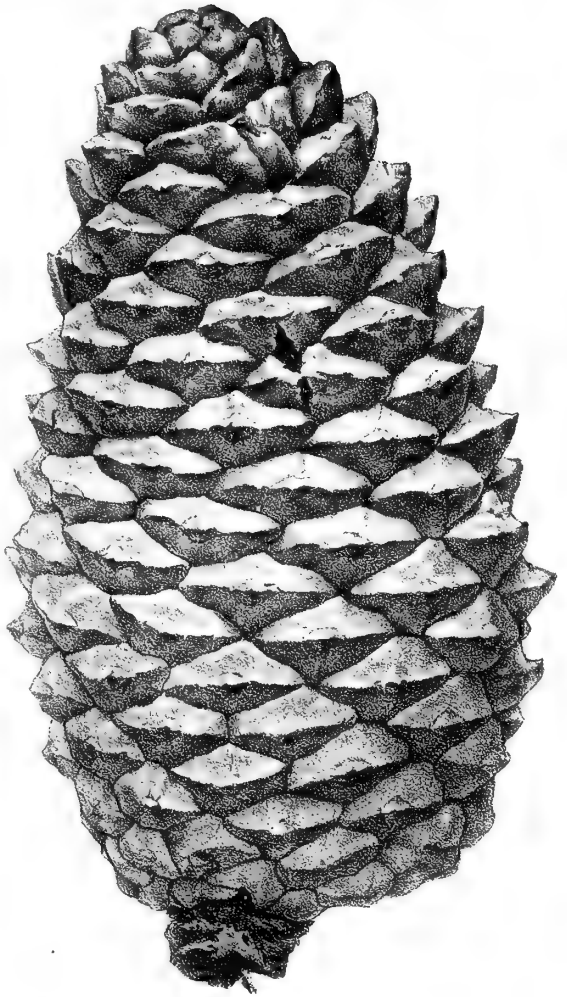
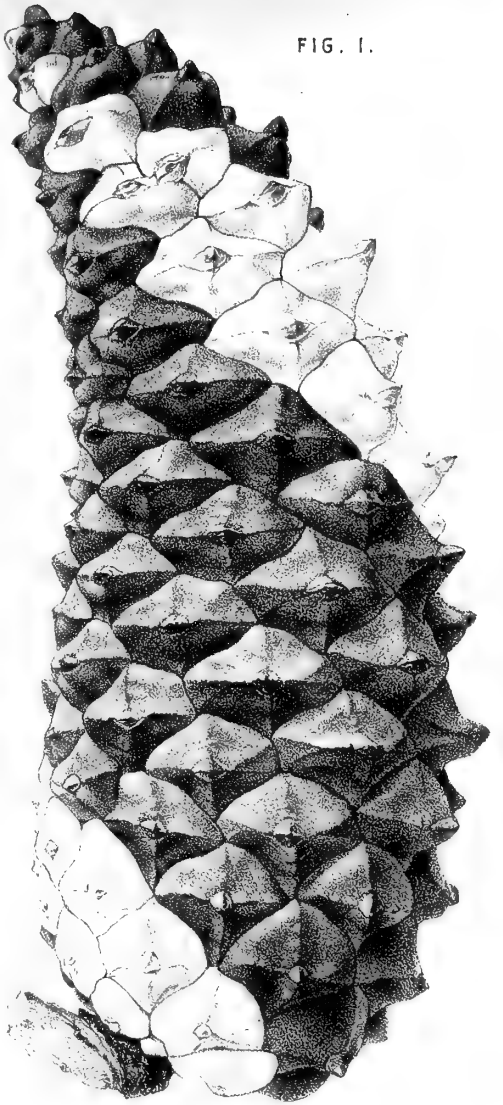


FIG. 1.



Mc Farlane & Erskine Lith.r Edin.r

NATURAL HISTORY

Fig. 1.

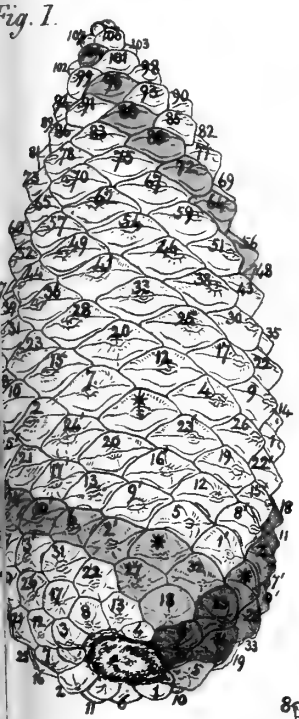


Fig. 6.

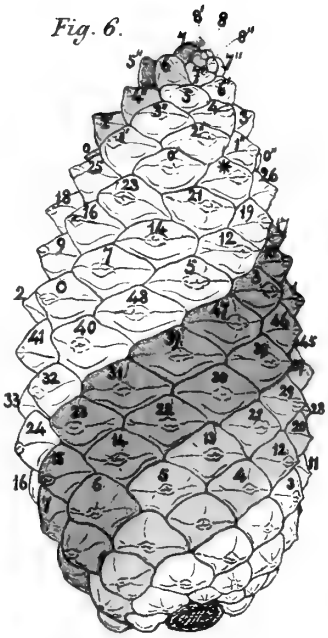


Fig. 7.

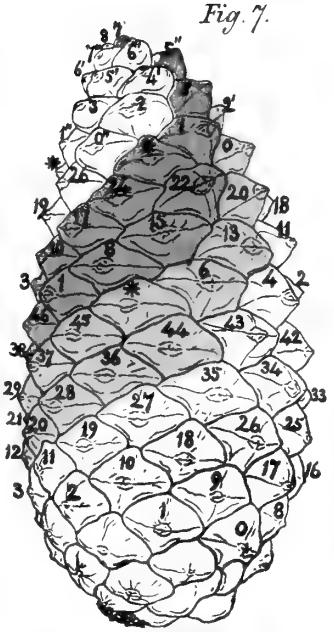
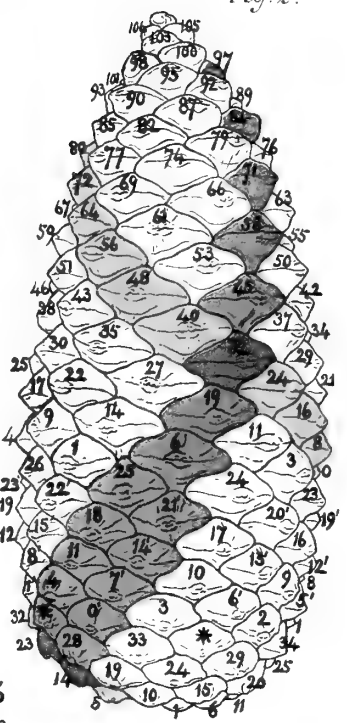


Fig. 2.



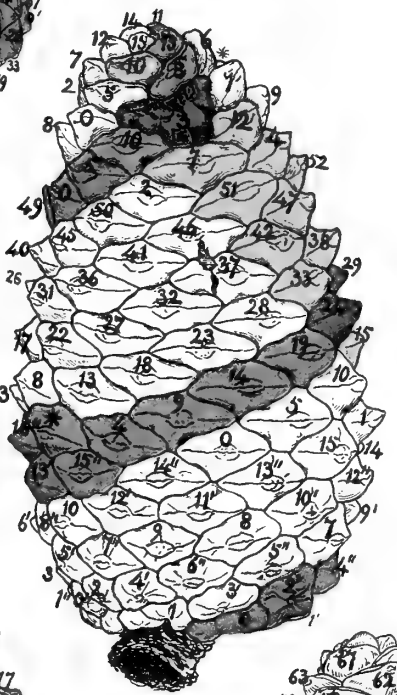


Fig. 4.

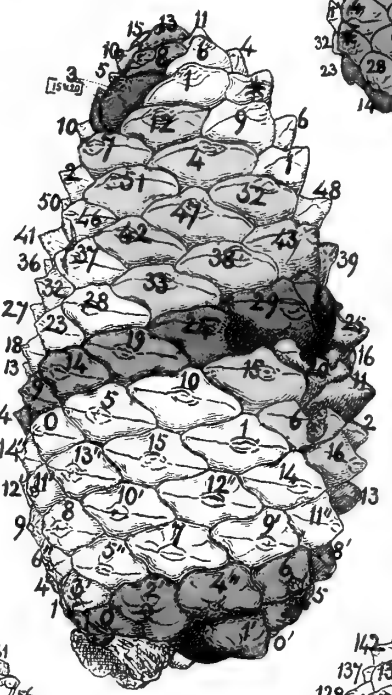
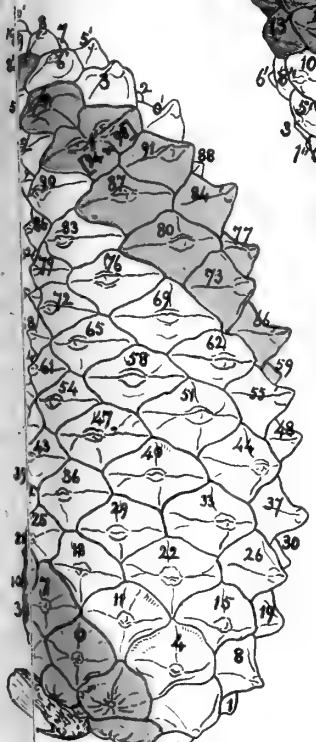


Fig. 5.



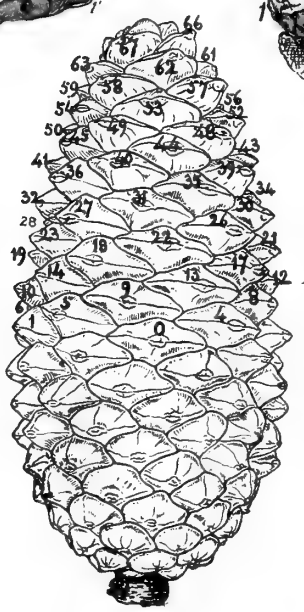


Fig. 8.

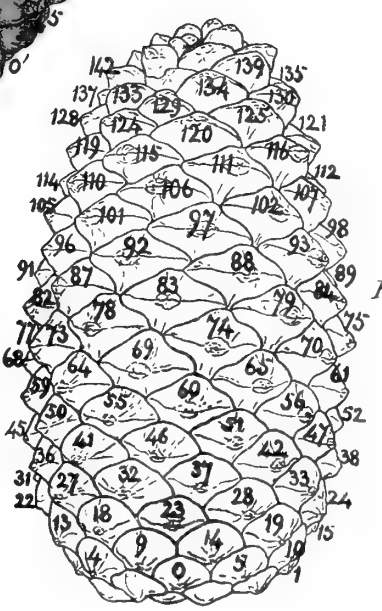


Fig. 9.

Photographs by A. Dickson, M.D.

M.c Farlane & Erskine, Lith.rs Edin.r

NATURAL HISTORY

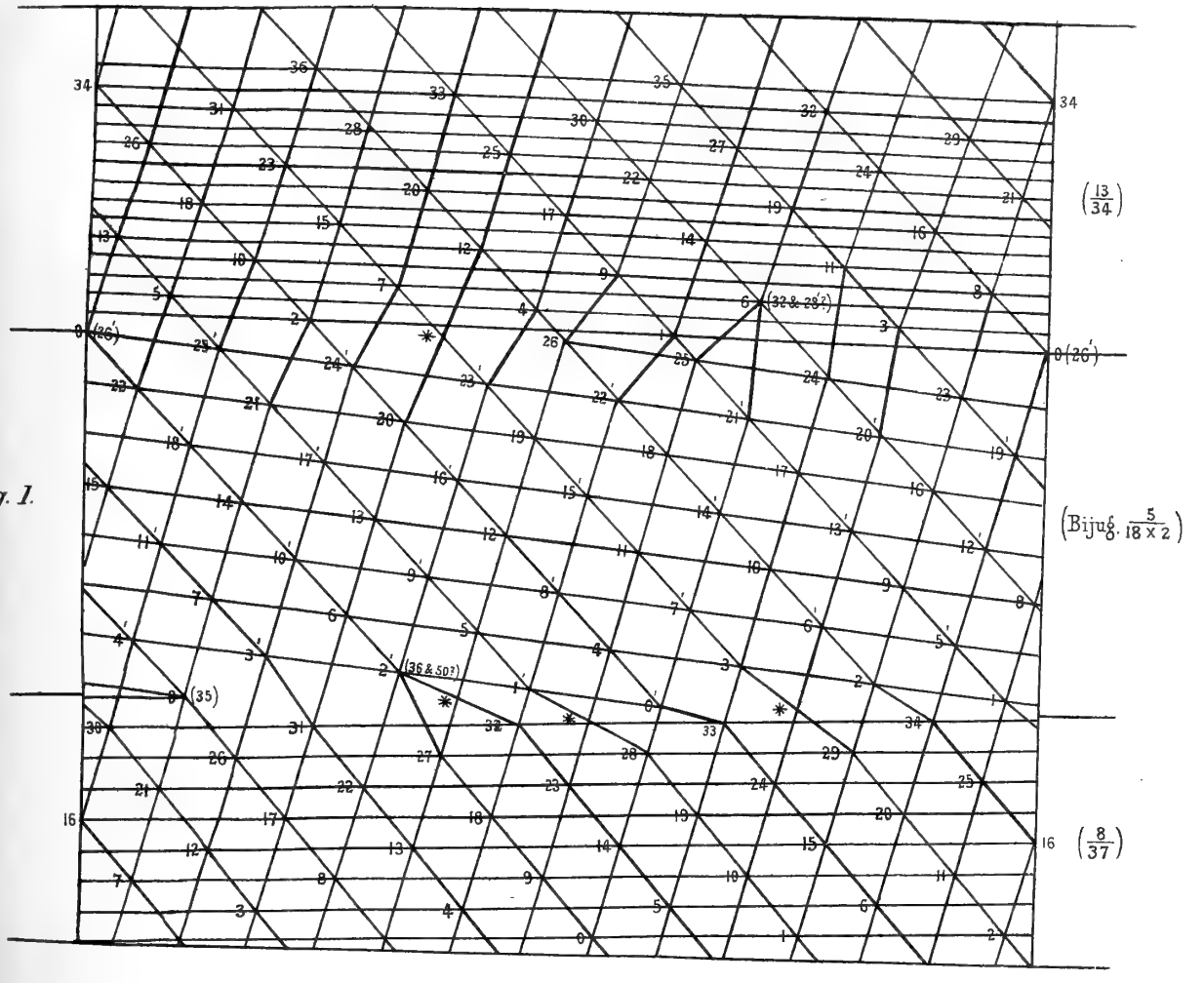


Fig. 1.

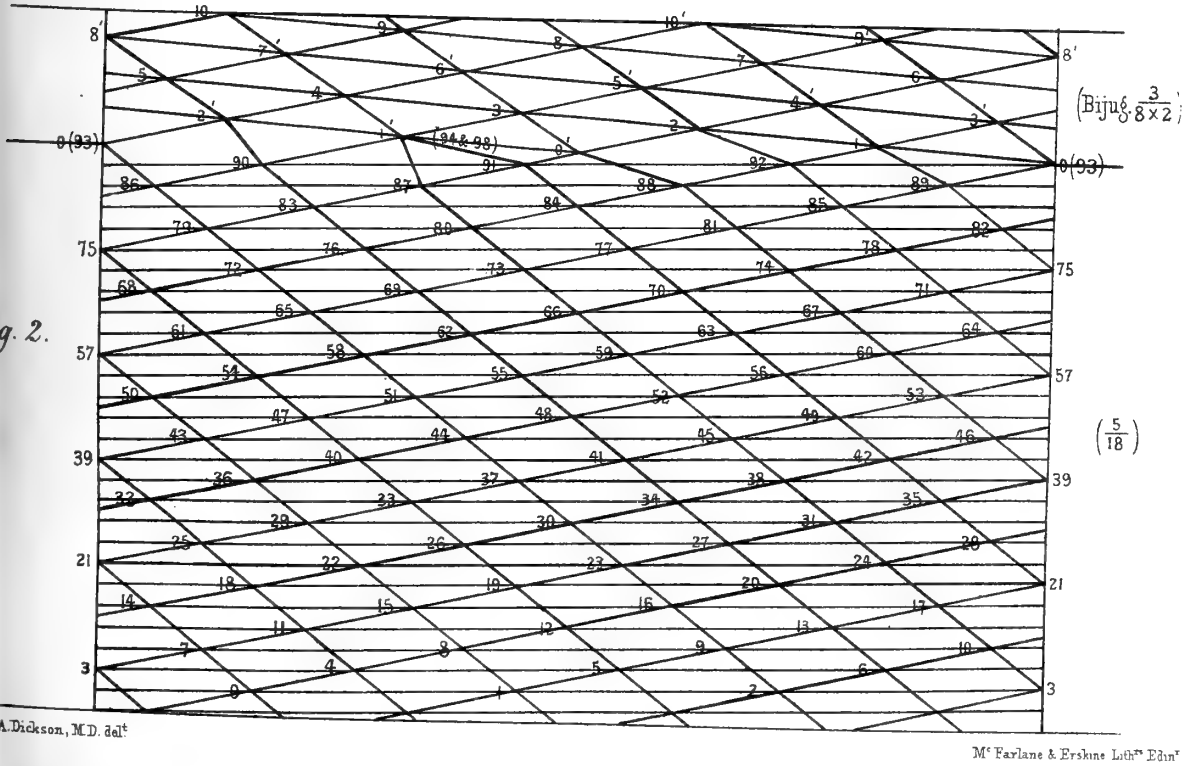


Fig. 2.

A. Dickson, M.D. delt

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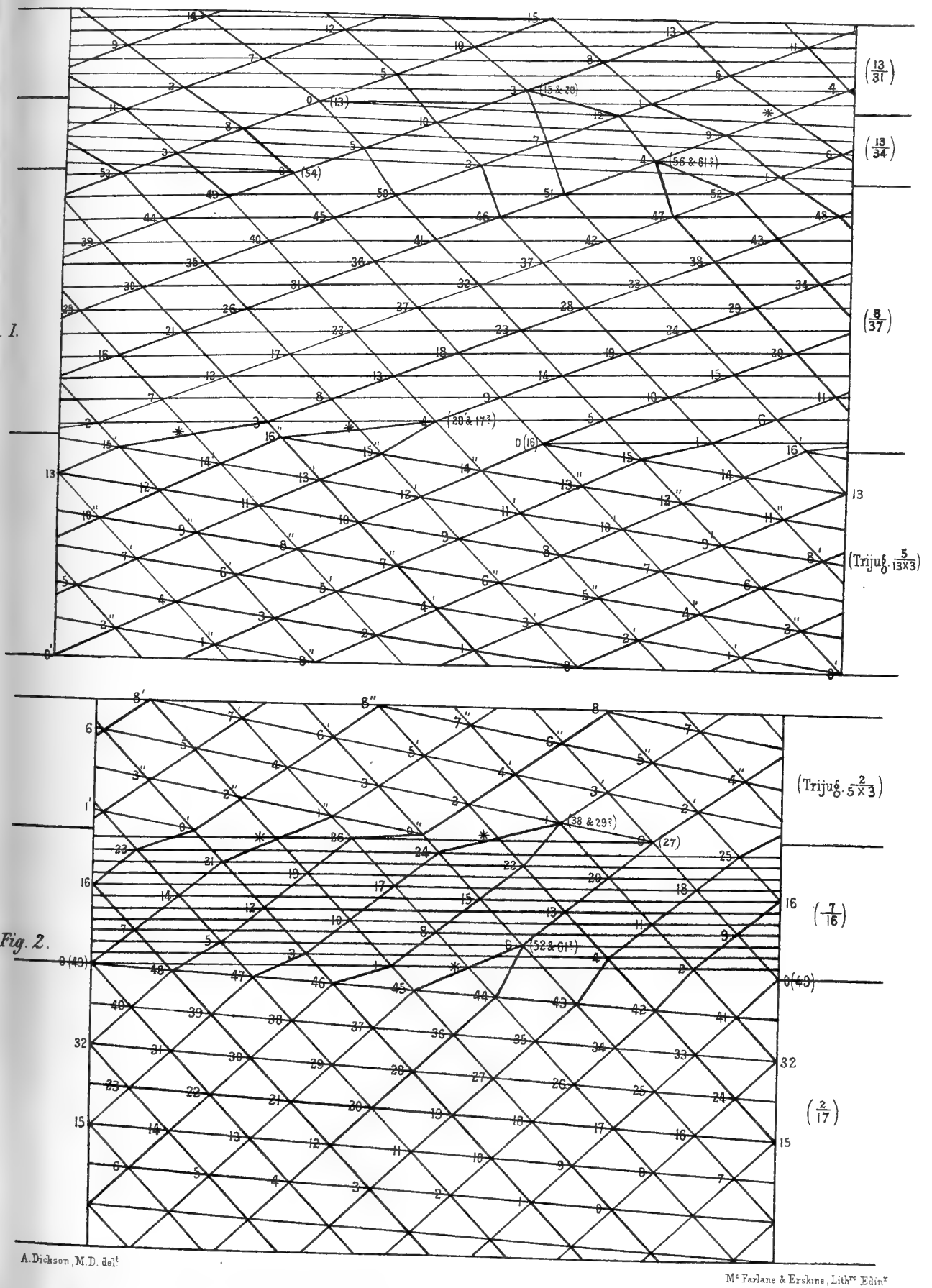


Fig. 1.

Fig. 2.

A. Dickson, M.D. del^t

Mc Farlane & Erskine, Lith^rs Edin^r

XX.—*Account of the New Table of Logarithms to* 200 000.

By Edward Sang, Esq.

(Read 20th February 1871.)

The essential character of all tabular aids to computation is, that the results of many operations are recorded in some systematic way for easy reference, and that thereby the computer is spared the toil of obtaining these results for himself.

In many cases this constitutes almost the whole advantage of the table. Thus when, instead of extracting the cube root of some number, we take it from a printed book, we are merely using another's labour. The gain to the calculating community is, that the oft-repeated extraction of the same root is avoided. We also gain by the facility of systematic calculation; the labour of computing a series of successive results being in general only a small fraction of that which would have attended the same work performed in a desultory manner.

The possession of a table of the corresponding values of two connected magnitudes enables us to perform the inverse operation, that of finding the argument from its function, an operation generally much more difficult than that of finding the function from the argument. Tables special to his own pursuits are thus indispensible to every investigator.

But tables of logarithms possess advantages of a peculiar nature. Except in a few rare speculations, no one desires to know a logarithm for its own sake; nor, in general, would that knowledge be of any use to us. The ability to compute the logarithm belonging to a number, or the number belonging to a logarithm would, of itself, be almost barren of useful result. If, in order to apply the neperian process to ordinary multiplication, we had to compute the logarithm of each factor, add these together, and thence compute the corresponding number, we should have expended a hundred times the labour of the ordinary process. Viewed abstractly, Napier's process is ridiculously circuitous; its whole advantage is and was intended to be derived from tabulation; so much so, that the mechanical operations of paper-making and printing enter among its constituent parts almost as essentially as the arithmetical computation itself. Napier's original conception was of a table to subserve certain ends, and his efforts were directed not to the discovery of a single logarithm, but to the construction of a logarithmic system. Here the table is everything.

From this example, the general principles which regulated the actual course of proceeding may be understood. Two things have to be kept in view when seeking for a convenient way of getting at the logarithm of a proposed prime number, one to get an easy divisor, the other to obtain by a change of sign the logarithm of some other number not previously found, preferably a prime number.

For example, we have filled the list of prime numbers up to 29, the logarithm of which has now to be found. Our first business is to search for some multiple of 29 which ends in 0001, or in 9999, in order that the divisor terminate in zeroes, the more the better; 29 ends in 9, and therefore we may use the divisor 30, which would also give us the logarithm of 31; this divisor, however, is too slow, so we carry on our search thus :—

$$\begin{aligned} 1 \times 29 &= 29 \\ 30 \times 29 &= 870 \\ \hline 31 \times 29 &= 899 \\ 900 \times 29 &= 26\,100 \\ \hline 931 \times 29 &= 26\,999 \end{aligned}$$

There the divisor 900 would have done, provided the logarithm of 31 had been known ; wherefore we proceed another step, which brings us to the divisor 27 000 ; this divisor is available if the logarithm of 931 be known. On turning to the filled-in table of natural numbers, we find the logarithm of 931 there; it had come from the product $7 \cdot 7 \cdot 19$. From 27 000 we also get 27 001, and therefore inquire whether this be a prime or a composite number. This research in itself would have been enormously tedious, so much so that any saving from the discovery of the factors would have been but a small set-off against the labour expended. That most admirable table, however, of the Divisors of Numbers constructed by BURKHARDT makes the matter easy;* it shows us that 27 001 is the product of $13 \cdot 31 \cdot 67$; so that once the logarithm of 31 is found, that of 67 also may be obtained. Wherefore, making $x = \frac{1}{72\,000}$, we obtain log 29 and log 27 001.

Subsequently making $x = \frac{1}{900}$ we have log 31, log 901, and log 53; and thence again log 97.

Here it may be proper for me to bear testimony to the great value of BURKHARDT'S work, which contains the divisors of all numbers up to three millions. The prodigious amount of labour, in the face of an expected small

* In this particular instance we might have done without BURKHARDT'S help, because $27\,001 = 30^3 + 1^3$ and so is divisible by $30 + 1$.

return, is only equalled by the scrupulous carefulness of the execution. For many years, and in various branches of research, I have habitually used the Table des Diviseurs, and only in one instance have found a fault,—that fault having been caused by a displacement of the types in the process of printing.

So long as the primes were under 1000, their logarithms were compared with those given by CALLET in his Tables Portatives to 60 places; and the coincidence was held as a sufficient check. In no one instance was an error found in CALLET. Afterwards, however, each logarithm was computed twice, generally once from a multiple ending in 01, and once from another ending in 99. At times the divisors were enormously large; thus, for the prime 653 the divisor 249 000 000 was used. In such cases the advantage of the second result was lost, since it would have been a matter of great labour to have found the divisors of 248 999 999. It would be still more laborious in the case of 7 580 000 001 attending the computation of the logarithm of 1277.

The computation of the logarithms of all the primes in succession to above 2000 was thus carried on, and those of many other primes incidentally found; these and the logarithms of their multiples up to 10 000 to twenty-eight places, having been written in their places, a sufficient groundwork was obtained for a table to fifteen places, beginning at 100 000, since the differences of the third order there count only in the sixteenth place.

Paper having been ruled, and the lines numbered from 100 000 to 150 000, the logarithms, but only to fifteen places, of the products of the numbers already found, were inscribed in their proper places; the first and second differences of these were taken wherever they happened to be sufficiently grouped together, and the gaps were then filled up by means of second differences.

These interpolations were easily accomplished, because, since the third differences are less than units in the fifteenth place, the progress of the second differences could be estimated. It was enough, then, to make trials with the last three figures of each order of differences; and after a little practice these trials were quickly made. The final figures of the second differences having thus been found, the others were obtained, and the first differences with the logarithms themselves were found by subtraction and addition.

In this way a table of fifteen-place logarithms for all numbers from 100 000 to 150 000 was formed.

To all who are familiar with extensive tabular work, it must be apparent that these results, though trustworthy on the whole, could not be depended upon as accurate in each item. A wrong figure may have been written, and yet, on account of the consecutiveness of the differences, may not have been detected by the subtraction. It became necessary, therefore, to revise the whole in such a way as to preclude this source of error.

For this purpose a new set of ruled pages were consecutively numbered, and

the last two figures only of the second differences were copied into their places; the first line of the first page, that is, the logarithm of 100 000, with the first and second difference complete, was also filled up by copying. The whole table was then re computed by continued summation, the results being compared, at each fifth step, with the previous work; but as this comparison was not made until the result was actually written down, the possibility of the transference of an error was avoided. In this way the new computation may be held as, in all probability, quite free from error, except, indeed, the minute errors inseparable from interpolation, and not exceeding one or two units in the fifteenth place.

This new computation was to serve at the compositor's desk; wherefore, for the purpose of keeping it clean and free from injury, the pages were transferred by the copying press, and the copy was made to serve both for the type-setting and for farther calculation. The original sheets were bound up for preservation, in volumes containing each 10 000 numbers.

The logarithms for the latter half of the new table were obtained from those of the first half by adding to each alternate logarithm the logarithm of 1·5. In this way each third logarithm was found; the intermediate ones being obtained by interpolation. To have constructed the table directly in this way would have left us liable to unchecked individual errors. In order to avoid these, or rather to convert them into running errors, which cannot fail to be detected, the following plan was followed:—

The last two figures only of the alternate logarithms were considered, and the last two figures of the second differences for interpolation were adjusted by trial on the slate, and, after being tested, were written in their places on the prepared paper. These trials are easily made, because, at this part of the table the third difference only amounts to ·25 of the fifteenth place, and, towards the end of the work, comes down to ·10 of the same. From these terminal figures the table was constructed by continuous summation as before, and each third result was checked by addition after having been written. This check also afforded a test of the accuracy of the preceding part, and, in point of fact, one solitary error was detected by it.

Thus, the whole manuscript table of fifteen-place logarithms, with their first and second differences, was constructed by continuous summation from 100 000 to 200 000, and may almost be held as free from any but last-place errors. It is contained in ten quarto volumes, which form the first ninth part of the manuscript table of all numbers up to one million.

The importance of having the printed table absolutely free from error, naturally brought up the question of the use of calculating machinery; and that question had to be very seriously considered. All the calculating machines hitherto contrived are capable merely of addition or subtraction. These opera-

tions are sufficient for our purpose. The only intrinsic difficulty is this, that the final differences change irregularly in the last place; wherefore, in using any machine for computing logarithms, the operator must set the final difference by hand preparatory to each step. The machine thus cannot properly be called self-acting; it is liable to errors caused by mistakes of the operator, who is under the necessity of examining each result. He dare not venture to overpass several steps, because one error may have balanced another in the intermediate work. If the instrument go only to the extent of the printed work the last digit would thus be insecure.

If, on the other hand, the instrumental work be carried to more places, in order that minute errors may not tell, the second differences would be brought into account, the machine would become enormously complex, and the expense of it would exceed many times what, in another way, may produce as good a result. Besides, the amount of attention, that is, of mental fatigue, would be much greater, and would be accompanied by a loss of time.

Again, the machine must not merely compute, it must record the results in some solid form capable of transferring impressions to paper. Only two ways have been proposed for this. One to cause the figures to be punched in a plate of soft metal from which electrotype casts may be taken; the other, to arrange moveable types by the machine. In the first way it is difficult to correct an error otherwise than by going over the whole page. In the second plan a wrong type may get into the group from which the figures are taken. In either way the results have to be carefully watched. Thus, do what we will, the last resort is to careful reading, and careful reading will accomplish the whole without any machine. The determination, therefore, was to proceed by the ordinary method of hand-setting.

The course actually followed did not differ essentially from the usual process. The types were set up in pages, proofs were taken, corrections made, and the pages were then subjected to the process of electrotyping. In two respects only did the course actually followed differ from the usual one. After the electrotype has been taken, the page is unlocked, and the types are distributed into their proper boxes to be ready for future use. The usual way is to make use of these types, which lie in disorder in the case. Instead of using the types directly after distribution, these types were set up in regular packets, so as to permit of the examination of their faces. In this way the errors of distribution were completely obviated. Moreover, the types were now placed in the case all ready arranged and in the position most convenient for the compositor, who was no longer obliged to examine the manner in which each individual type happened to be lying in its box, and who could now take up the types without almost looking off his paper. By this arrangement the errors in composition

were themselves much lessened, while those of distribution, twenty or thirty times as numerous, were entirely removed.

The other change was in taking two electrotypes of each page, one set to be used for printing, the other set to be reserved for the sole purpose of reproducing working plates. In this way, as any errors which may be detected are to be corrected in the reserved as well as in the working plates, the table will eventually come to be entirely freed from faults.

It is now two centuries and a half since the logarithmic table was completed to 100 000. The want of a greater extension has been felt by the few computers engaged in researches requiring great precision; and in 1819 a proposal was made in the House of Commons, that our Government should join with that of France in the publication of new Logarithmic and Trigonometric tables. No actual progress, however, was made.

It is then worth while to record the extension of the seven-place tables to twice the usual length; particularly when that is accompanied by the finished calculations for one-ninth part of the million table. Which ninth part really implies more than one half of the calculations needed to reach the next step in the denary scale.

DIAGRAM 1. ILLUSTRATING THE 1ST SERIES OF EXPERIMENTS, IN WHICH ATROPIA WAS ADMINISTERED FIVE MINUTES BEFORE PHYSOSTIGMA

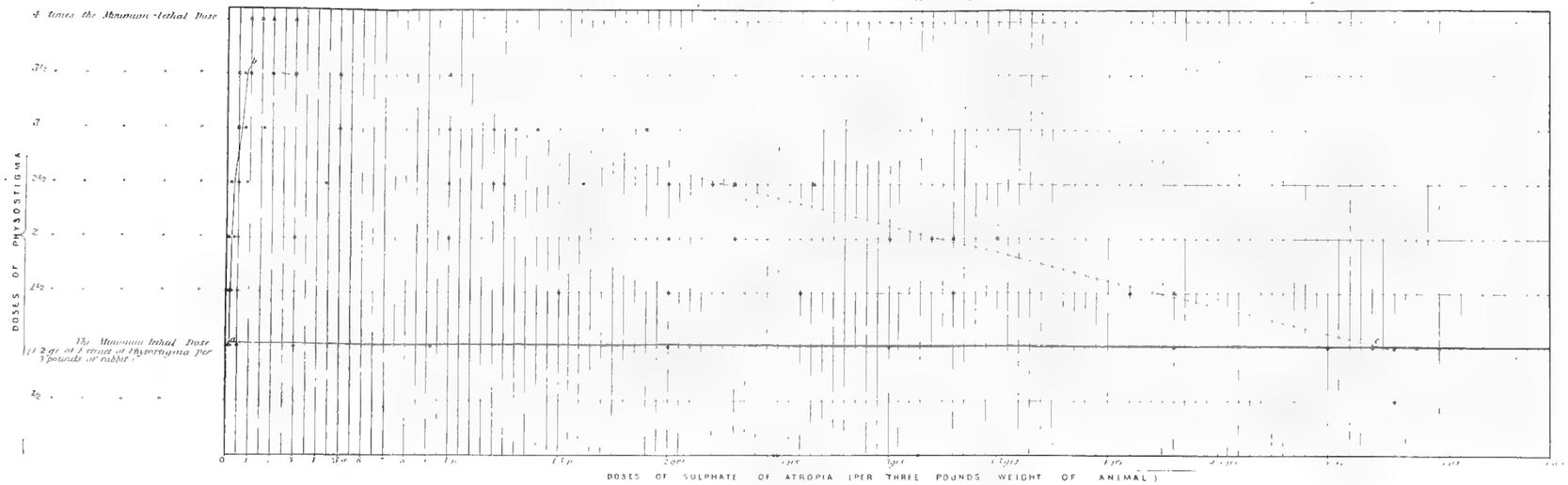


DIAGRAM 2. ILLUSTRATING THE 1ST SERIES OF EXPERIMENTS.

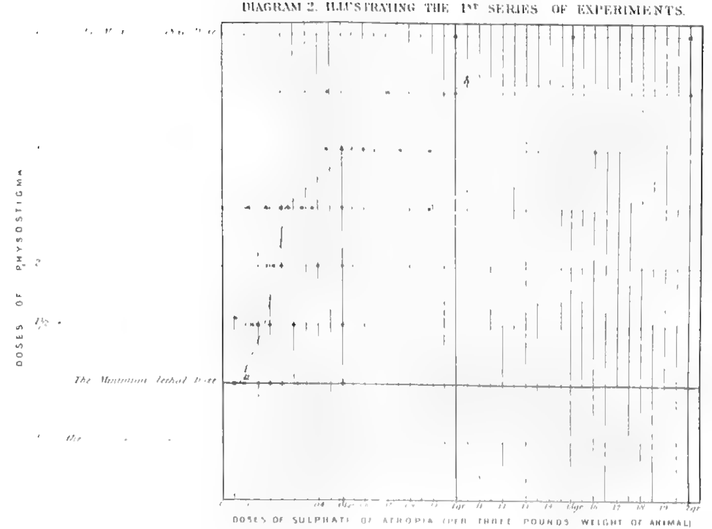


DIAGRAM 3. ILLUSTRATING THE 2ND SERIES OF EXPERIMENTS IN WHICH ATROPIA WAS ADMINISTERED FIVE MINUTES AFTER PHYSOSTIGMA

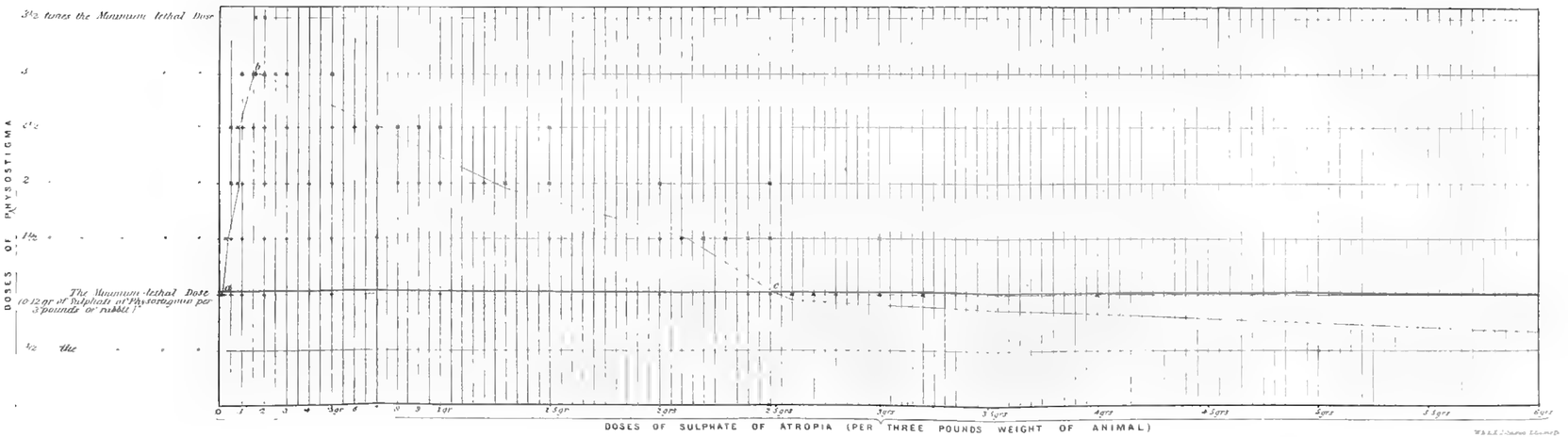
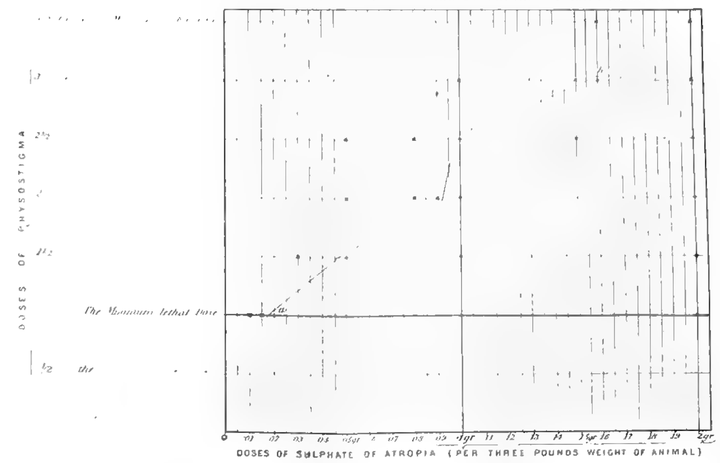


DIAGRAM 4. ILLUSTRATING THE 2ND SERIES OF EXPERIMENTS.



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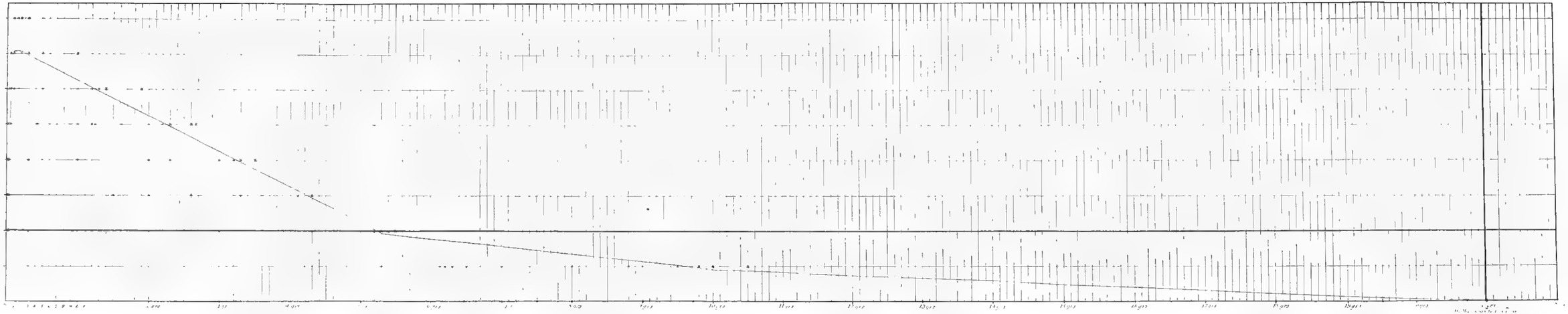
NATURAL HISTORY.

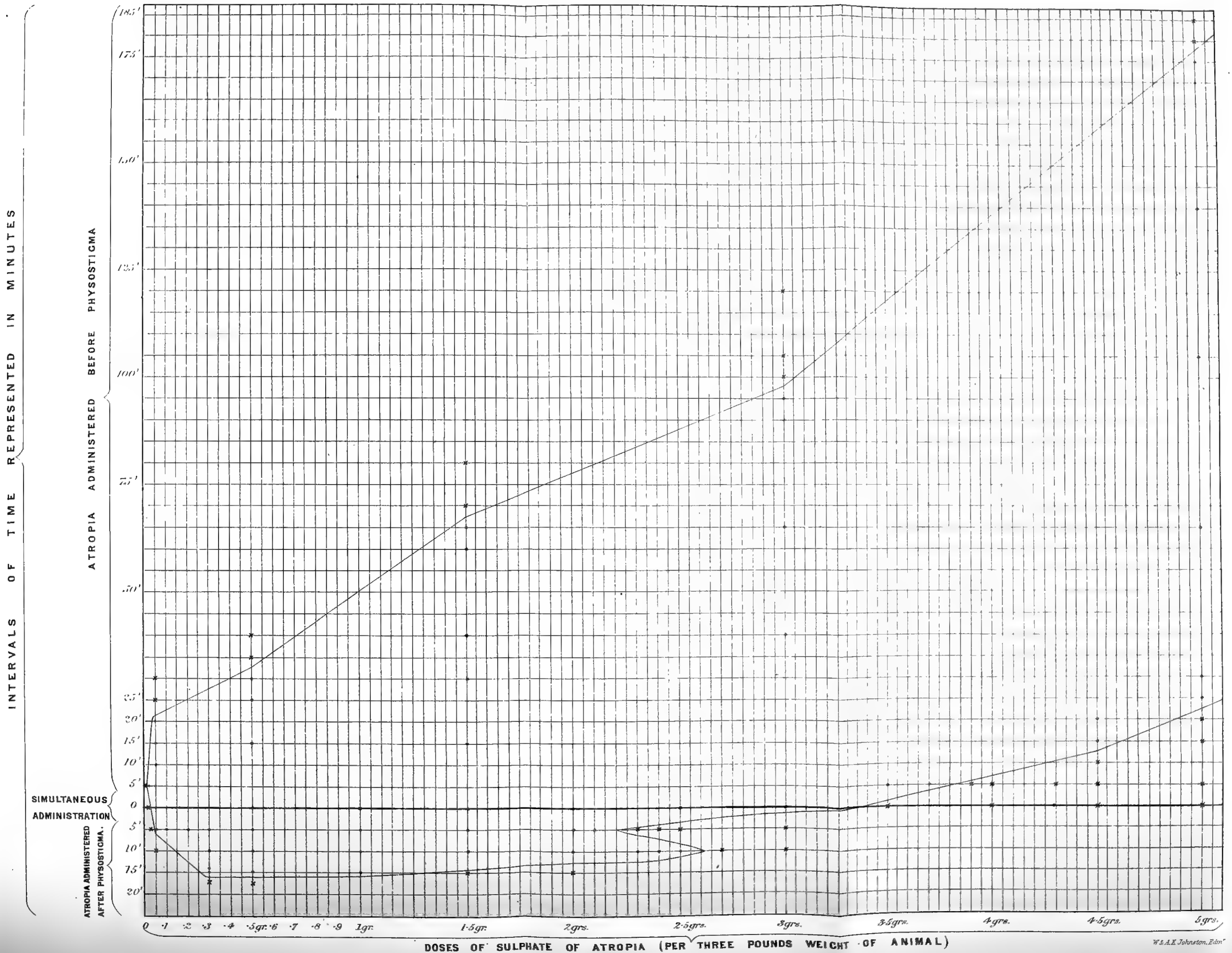
DIAGRAM 5. ILLUSTRATING THE 1ST SERIES OF EXPERIMENTS, IN WHICH ATROPIA WAS ADMINISTERED FIVE MINUTES BEFORE PHYSOSTIGMA.
(THE ENTIRE REGION OF RECOVERY WITH NON-LETHAL AS WELL AS WITH LETHAL DOSES OF PHYSOSTIGMA IS REPRESENTED.)



DOSES OF SULPHATE OF ATROPIA (PER THREE POUNDS WEIGHT OF ANIMAL.)

NATURAL HISTORY

DIAGRAM 6. ILLUSTRATING THE 3RD SERIES OF EXPERIMENTS. IN WHICH THE DOSE OF PHYSOSTIGMA WAS CONSTANT (ONE AND A HALF TIMES THE MINIMUM-LETHAL DOSE), WHILE THE DOSE OF ATROPIA AND THE INTERVAL OF TIME BETWEEN THE ADMINISTRATION OF THE TWO SUBSTANCES VARIED.



XXI.—*An Experimental Research on the Antagonism between the Actions of Physostigma and Atropia.*

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(Read 29th May 1871.)

INTRODUCTION.

It is natural to suppose that soon after it became known that injurious effects follow the introduction of certain substances into the system, attempts were made to remedy these effects, and also to discover counteragents, or antidotes, to the hurtful substances. The success attending these attempts must, of necessity, have been closely related to the existing state of knowledge regarding the actions of active substances. When the effects of poisons were referred to supernatural manifestations, it was chiefly charms and superstitious rites that were trusted to as protectives and remedies. At a somewhat more advanced period in the progress of human knowledge, vague notions of physiological laws and processes supplied the indications of curative treatment. Alexipharmics, Mithridates, and theriacæ were compounded of substances possessing eliminative and so-called "general stimulant" properties, and bezoars of such as enjoyed a reputation as specifics against poisonous influences; and these were employed, almost indiscriminately, as universal antidotes. Still later, chemistry suggested that, as the physical properties of poisons may be modified by various re-agents, so may their effects be prevented by the administration of suitable substances.

The recommendations derived from chemistry were at first only of the crudest description; but as the science advanced, many valuable hints were obtained, and now the class of the chemical antidotes probably includes the largest number of efficient counteragents to poisons. Alkalies and acids are employed to neutralise each other, tannin to render insoluble tartar emetic and many vegetable alkaloids, hydrated sesquioxide of iron to precipitate arsenious acid, and soluble and inert sulphates to decompose lead salts, and render them unabsorbable. In these examples, as well as in the many others belonging to this class, the operation of the antidote is limited to the chemical change it produces on the poison while it remains in the alimentary canal. As soon as the poison becomes absorbed into the blood, it appears to pass beyond the antidotal influence of the chemical counterpoison, for no example exists of a chemical antidote neutralising a poison after absorption. Thus it is that the value of such antidotes is considerably restricted.

Physiological Antagonism.

Localised Antagonism. — In order perfectly to neutralise the effects that follow the introduction of a poison into the living economy, it would appear to be necessary that the physiological functions of the affected organism should be modified. The early, though, undoubtedly, crude notions that originated the employment of alexipharmics, Mithridates, and theriacæ, to a certain extent recognised this principle. The more perfect knowledge acquired within recent times regarding the functions of structures and organs, has led to the discovery that various substances are able to modify them in a definite and constant manner, and that the modifications produced by certain substances are of a nature contrary or opposite to that of those produced by others. By such observations, the existence of physiological antagonism between certain of the effects of different active substances has been demonstrated. Several apparently well-authenticated examples have been made known: among which may be instanced the antagonism between the actions on the iris and on the minute blood-vessels, of opium or morphia on the one hand, and belladonna, hyoscyamus, and stramonium on the other; between the actions on the capillary circulation of morphia and quinia; between the actions on the vagi nerves of physostigma and atropia, hydrocyanic acid and atropia, and muscaria and atropia; and between the actions on the iris and on visual accommodation of physostigma and atropia.

General and Lethal Antagonism.—In some instances, the existence of such limited counteractions has led to the supposition that the general, or, at least, the primary lethal action of one of the substances concerned is capable of being antagonised by the physiological action of the other. A notable instance of this is to be found in the revival, by the late Dr Thomas Anderson, in 1854, of the old, but, at that time, almost forgotten doctrine, that belladonna is a physiological antidote to the poisonous action of opium.* Anderson was led to this idea from the fact that these two substances produced contrary effects on the iris. The occurrence of an antagonism limited to a single organ in no important degree related to the continuance of life is, however, an insufficient reason for supposing that the general actions of any two substances are of an antagonistic nature. In order legitimately to infer whether one substance is capable of acting as a physiological antidote to another, it is necessary to acquire a definite knowledge of the exact nature of the general physiological action exerted by each of them. As yet the action of only a few substances has been ascertained with the completeness that is required; and hence it is that the examples that have been advanced of general antagonism between the actions

* Edinburgh Medical and Surgical Journal, vol. xviii. 1854, p. 377.

of active substances are but few in number, while the evidence on which these examples have been founded is generally imperfect.

Between Opium and Belladonna, Hyoscyamus or Stramonium.—Among the various instances in which a general antagonism has been stated to exist between the actions of active substances, in the sense that the lethal effect of the one substance is capable of being prevented by the physiological action of the other, the most familiarly known is that where the substances are, on the one hand, opium, and, on the other, belladonna, hyoscyamus, or stramonium. The existence of a belief in the power of belladonna to counteract the general physiological action of opium, may be referred to so early a date as the year 1570, when it was recorded by PETRO PENA and MATHIA DE LOBEL that certain Italian peddlers gained much notoriety by employing the root of the belladonna plant to quench thirst, and by administering opiates to remedy the evil effects that were occasionally produced thereby.* In 1661, HORSTIUS reported a case in which the injurious effects of a large dose of the inspissated juice of belladonna were apparently removed by the use of opium.† Soon afterwards, FABER related a somewhat similar experience;‡ and, in 1766, BOUCHER, of Lille, published five cases of poisoning by belladonna berries, in two of which opium was administered as an antidote.§ At the commencement of the present century, JOSEPH LIPPI wrote an inaugural dissertation, "De veneficio baccis belladonnæ producto atque opii in eo usu," in which were recorded, according to GIACOMINI, "pleusieurs guérisons à l'aide de laudanum de SYDENHAM."‖ GIACOMINI himself expresses a favourable opinion regarding the beneficial effects of opium in poisoning by belladonna; and mentions, further, that the Italians were accustomed to administer opium to remove the stupor and convulsions that follow excessive doses of hyoscyamus and stramonium. Within more recent times, many modern authors, as ANGELO POMA,¶ ANDERSON,** CAZIN,†† BENJAMIN BELL,‡‡ BÉHIER,§§ LEE,‖‖ NORRIS,¶¶ and CONSTANTIN PAUL,*** have published evidence that appears to favour a belief in the existence of this antagonism. This evidence has been derived from cases of poisoning in man by opium, in which belladonna, hyoscyamus,

* Stirpium Adversaria Nova, authoribus PETRO PENA et MATHIA DE LOBEL, Medicis. Londini, 1570, p. 103. (Quoted by DR NORRIS, The American Journal of the Medical Sciences, vol. xliv. 1862, p. 399.)

† Opera Medica. ‡ Strychnomania, 1677.

§ Journal de Médecine, Chirurgie et Pharmacie, etc., tome xxiv. 1776, pp. 310–332.

‖ Traité philosophique et expérimental de Matière Médicale et Thérapeutique, traduit par MAJON et ROGNETTA, 1839, p. 537.

¶ Gazette Hebdomadaire, 10 Avril 1863. ** *Loc. cit.*

†† Traité des Plantes Médicinales Indigènes, 1855.

‡‡ The Edinburgh Medical Journal, vol. iv. 1859, pp. 1–7.

§§ L'Union Médicale, Juillet 1859.

‖‖ The American Journal of the Medical Sciences, vol. xliii. January 1862, p. 54.

¶¶ Ibid., vol. xliv. October 1862, p. 395.

*** De L'Antagonisme en Pathologie et en Thérapeutique, 1866, pp. 92–115.

or stramonium was used as a physiological antidote; and, conversely, of poisoning with one or other of the latter substances, in which opium was used as an antidote. In presence of the numerous important fallacies that are inseparably connected with such evidence, it would be vain to expect that from it alone an absolute demonstration could be obtained of the existence of a general antagonism so perfect as to constitute any one active substance the physiological antidote of another. This evidence must, therefore, be regarded as unsatisfactory, more especially as several observers of recognised ability, as Dr JOHN HARLEY* and L. ORFILA,† have pronounced it insufficient, after a careful examination of the record of each case.

The general result of the investigations that have been made to decide this question by experiments on the lower animals, is also of an inconclusive character. No doubt, the experiments of BOIS,‡ CAMUS,§ ONSUM,‖ and BROWN-SEQUARD¶ appear to show that the lethal action of opium cannot be prevented by the physiological influence of belladonna, hyoscyamus, or stramonium, nor that of the latter substances by opium; but these experiments are open to the objection, that the doses of the substances used as antidotes do not seem to have been sufficiently varied.

At the same time, there can be little doubt that the evidence derived from both clinical observation and experimental research is sufficient to show that several of the actions of opium are of a contrary nature to those of belladonna, hyoscyamus, and stramonium.** It is, however, equally undoubted that, in the meantime, this evidence is insufficient to *prove* the existence of a general antagonism; or of one between actions of sufficient importance to constitute opium a physiological antidote to belladonna, hyoscyamus, or stramonium, or these latter substances physiological antidotes to opium. The question still remains an open one; but such knowledge as is already possessed renders it probable that a general antagonism does really exist, to the extent, at any rate, of the primary lethal action of opium or morphia being preventable by the physiological action of belladonna, hyoscyamus, or stramonium. A properly devised series of experiments would in all likelihood justify the opinion of those who, with no little courage, have practically affirmed their belief in the existence of this antagonism.

* The Old Vegetable Neurotics, 1869.

† Dictionnaire Encyclopédique des Sciences Médicales (Atropine), tome vii. 1867, p. 215.

‡ Gazette des Hôpitaux, 1864.

§ Etude sur l'antagonisme de l'opium et de la belladonne. Thèse de Paris, 1865.

‖ Schmidt's Jahrbucher, 1865, Bd. 128, p. 288.

¶ Journal de la Physiologie de l'homme et des animaux, tome 3me, 1860, p. 726.

** Interesting accounts of several of these contrary actions, founded on careful clinical observation, have been published by Drs MITCHELL, KEEN, and MOREHOUSE (see their paper "On the Antagonism of Atropia and Morphia," in the American Jour. of the Med. Sciences, Vol. L. 1865, p. 67; and also by Dr ERLENMEYER (for an abstract of whose paper, see "L'antagonisme de l'opium et de la belladonne," by Dr RAYNAUD, Paris, 1866, p. 40).

The recent development of the study of Pharmacology has led not only to the acquisition of knowledge regarding the exact manner in which many active substances influence the physiological conditions of vital structure, but also to the differentiation of the special structures, by the modification of whose physiological conditions the lethal action of these substances is produced. In a few instances it has been shown that the nature of the modification produced in the physiological condition of the structure or structures involved in the lethal action of the substance is apparently contrary to that produced on the same structure or structures by the physiological action of another substance. The establishment of such facts has led, within the last few years, to the suggestion of two instances of antagonism,—the first being between the lethal action of prussic acid and the physiological action of atropia, and the second between the lethal action of muscaria and the physiological action of atropia.

Between Atropia and Prussic Acid.—For the first of these instances Pharmacological science is indebted to Professor PREYER of Jena. In the course of an elaborate research* on the action of prussic acid,—a research that may fairly be characterised as the most important that has yet been made on the action of this substance,—PREYER established that the primary lethal action is due to embarrassment of the respiratory and cardiac functions. He further showed that the embarrassment of the former function is caused by stimulation of the terminations of the vagi nerves in the lungs, and by impairment of the activity of the respiratory nerve-centre, while the embarrassment of the latter function is caused by excessive stimulation of the inhibitory cardiac fibres of the vagi nerves. Previous investigators—more especially Von BEZOLD and BLŒBAUM†—had already shown that atropia produces effects that are in a remarkable manner contrary to these; for, in certain doses, it accelerates both the respiratory and the cardiac movements,—the former, by paralysing the terminations of the vagi nerves in the lungs, and by stimulating the respiratory nerve-centre, and the latter, by paralysing the inhibitory cardiac fibres of the vagi nerves. Guided by these facts, PREYER made a few experiments which strongly support the opinion he has arrived at, that atropia is a physiological antagonist to prussic acid, even to the extent of being able to prevent the primary lethal action of that poison. It is, however, to be regretted that no attempt was made absolutely to demonstrate that the dose of prussic acid used in each experiment was a lethal one, more especially as the subsequently performed experiments of Professor BARTHOLOW—limited, no doubt, in their scope—do not seem to confirm PREYER'S opinion.‡

* Die Blausäure. Physiologisch Untersucht. Von W. PREYER, Dr. Med. et Phil. Bonn, 1870.

† Ueber die physiologischen Wirkungen des schwefelsauren Atropins. Von A. v. BEZOLD und Dr FRIEDR. BLŒBAUM. (Untersuchungen aus dem physiologischen Laboratorium in Würzburg. 1867.)

‡ The Physiological Effects and Therapeutical Uses of Atropia and its Salts, 1869, p. 25.

Between Atropia and Muscaria.—The second of the instances mentioned was first made known by SCHMIEDEBERG and KOPPE, in a very interesting memoir on Muscaria, published in 1869.* This active principle was separated by them from *Agaricus muscarius*, L., and found to possess an action in many respects contrary to that of atropia. The general nature of its lethal action was observed to be similar to that of prussic acid; and, accordingly, the reasons which induced SCHMIEDEBERG and KOPPE to examine as to an antagonism between it and atropia were analogous to those by which PREYER was led to investigate the influence of atropia in counteracting the primary lethal action of prussic acid. In this instance, likewise, only a very few experiments were made. Their results, however, are strongly in support of the existence of a more or less general physiological antagonism between the two substances.

Various other instances of General and Lethal Antagonism.—In addition to these, many other examples of general or of lethal antagonism have been advanced. Their existence, however, has rarely been inferred from a knowledge that the substances concerned influence the same structures in contrary modes, but has been conjectured from a knowledge merely of the general phenomena which are produced by these substances. The conspicuous spasmodic effects by which the action of strychnia is characterised, appear to have suggested the employment, as physiological counteragents, of various substances whose general action includes the production of paralysis; and, accordingly, the list of proposed antagonists to this alkaloid includes opium,† curara,‡ aconite,§ nicotia,‖ bromide of potassium,¶ chloroform,** chloral,†† and nitrite of amyl.‡‡ Opium and quinia have been proposed as antidotes to each other, because the former exalts several of the organic functions, whilst the latter depresses them.§§ General antagonism has been inferred between chloroform and sulphuric ether, solely on the ground that the anæsthetic action of the former is supposed to be accompanied with depression, and that of the latter with excitement ;‖‖‖ and the

* Das Muscarin. Das Giftige alkaloid des Fliegenpilzes. Von Dr OSWALD SCHMIEDEBERG und Dr RICHARD KOPPE. Leipzig, 1869.

† PELLETIER et CAVENTOU. See Dictionnaire Encyclopédique des Sciences Médicales (Antidote), tome 5me, 1866, p. 322.

‡ L. VELLA. Comptes Rendus des Séances de l'Académie des Sciences, xlix. 1859, p. 330, and li. 1860, p. 353.

§ E. WOAKES. The British Medical Journal, October 26, 1861, p. 440.

‖ S. HAUGHTON. Dublin Quarterly Journal of Medical Science, August 1862.

¶ F. A. SAISON. Du Bromure de Potassium et de son Antagonism avec la Strychnine. Paris, 1868.

** T. GALLARD. Annales d'Hygiène publique et de Médicine Légale, t. xxiv. 1865, pp. 182–184.

†† OSCAR LIEBREICH, Comptes Rendus des Séances de l'Académie des Sciences, lxx. 1870, p. 403; BENNETT, Edinburgh Medical Journal, 1870, v. 16, part 1, p. 262; GROVES, Medical Press and Circular, 1870, p. 398.

‡‡ J. ST CLAIR GRAY. Glasgow Medical Journal, February 1871, p. 188.

§§ GUBLER. Société Médicale des hôpitaux, 10 Février, 1858; and Commentaires Thérapeutiques du Codex Medicamentarius, 1868, p. 591.

‖‖‖ FALIN. Thèse, 1860. (Quoted by CAMUS, *op. cit.* p. 122.)

physiological actions of iodine and bromine are said to neutralise each other because the former produces sedation, and the latter excitation of certain general functions.*

Among these examples there are several worthy of further examination, and it is not impossible that their existence may thereby be established. Meanwhile, the criticism of the Professor of Therapeutics at Paris, in reference to the majority of recorded examples of antagonism, appears to be a just one, that "la précision fait souvent défaut dans l'analyse des faits, les inductions manquent de rigueur, et la pratique attend de nouvelles lumières de la part de la physiologie expérimentale et de la thérapeutique rationnelle."†

Between Physostigma and Strychnia.—This criticism is also applicable to much that has been advanced regarding antagonism between physostigma and certain other substances. The first instance that has been suggested of an antagonism in which physostigma is concerned, is that between it and strychnia. The spinal excitant action of the latter substance was naturally looked upon as more or less contrary to the paralysing influence exerted by physostigma on the spinal cord. In a paper published by me in 1862,‡ an experiment is described which lent some countenance to this surmise. Since that time experiments have been made by NUNNELEY,§ VÉE,‖ and EBEN WATSON,¶ which, on the whole, support the opinion that the spasmodic effects of strychnia may be diminished by the paralysing action of physostigma. They are, however, insufficient to decide whether the lethal action of the one substance can be prevented by the physiological action of the other.

Between Physostigma and Chloral.—In the remaining instance, the power of chloral to counteract the lethal action of physostigma has been experimentally tested by Professor BENNETT. It is, however, impossible to decide how far the opinion expressed by this observer, that chloral has a most marked influence in counteracting the lethal action of physostigma, is justified by the results of his experiments, as only a very brief account of them has as yet been published.**

* GUBLER. Bulletin Général de Thérapeutique, tome lxvii. 1864, p. 9.

† GUBLER. Dictionnaire Encyclopédique des Sciences Médicales (Antidote), tome 5me, 1866, p. 322.

‡ "On the Characters, Actions, and Therapeutic Uses of the Ordeal Bean of Old Calabar." Edinburgh Medical Journal, vol. ix. 1863, p. 245; and reprint, p. 19. See also, "On the Physiological Action of the Calabar Bean." Transactions of the Royal Society of Edinburgh, vol. xxiv. part iii. 1866–7, p. 740.

§ "On the Calabar Bean: its Action, Preparations, and Use." Lancet, 1863; and pamphlet, pp. 12–15.

‖ Recherches Chimiques et Physiologiques sur la Fève du Calabar (Thèse). Par le Dr AMÉDÉE VÉE. Paris, 1865, pp. 28–30.

¶ "On the Physiological Actions of the Ordeal Bean of Calabar, and on its Antagonism to Tetanus and Strychnia Poisoning." Edinburgh Medical Journal, vol. xii. May 1867, p. 999; and reprint, pp. 17–25.

** "On Chloral in Phthisis, and its Antagonism to the poisonous effects of Calabar Bean." The Practitioner, vol. iv. 1870, p. 262.

This account, however, does not very obviously support Professor BENNETT's opinion; for, of the eight experiments mentioned, in which rabbits were subjected to the influence of the two substances, seven terminated in death, and only one in recovery. Further, there is no evidence to show conclusively that the rabbit that formed the subject of the apparently favourable experiment had received a dose of physostigma sufficient to have caused its death had no chloral been administered.

In the preceding historical sketch every important alleged example of antagonism has been referred to. It has been shown that although in many cases the *à priori* reasons in favour of the existence of a lethal or of a more or less general antagonism are extremely plausible, the experimental data by means of which it has been attempted to establish the reality of the antagonism are probably, without exception, imperfect, and therefore insufficient to do so. I trust, however, that the description of the research forming the subject of the present communication will render it obvious that the reality of a lethal antagonism may be readily and certainly established by experiment.

ANTAGONISM BETWEEN THE ACTIONS OF PHYSOSTIGMA AND ATROPIA.

This research on the antagonism between the actions of physostigma and atropia was commenced in April 1868, and the results of some of the earlier experiments were published in a preliminary note read before this Society, on the 30th of May 1869.* In this note were described a number of experiments, which prove that the lethal action of physostigma may be prevented by the physiological action of atropia.

Previous to this time, however, the attention of more than one observer had been attracted to the subject. In 1864, KLEINWÄCHTER narrated an interesting case of poisoning with an unknown quantity of atropia, in which the internal administration of physostigma produced a marked amelioration of the symptoms.† Three years subsequently, BOURNEVILLE, of Paris, in a paper on the treatment of tetanus by physostigma,‡ described an experiment in which he, in the first place, introduced into the stomach of a cabiai a quantity of powdered kernel of physostigma, sufficient, in his opinion, to cause death, and then, while severe symptoms were present, injected subcutaneously a small quantity of atropia, with the result that the symptoms quickly diminished in severity, and the cabiai ultimately reassumed a normal condition. At the time when my preliminary note was published, BOURNEVILLE's experiment was quite unknown to me, and it is with much satisfaction that I now draw attention to it as an independent observation harmonising with the results I had obtained when my

* Proceedings of the Royal Society of Edinburgh, 1868–69, pp. 587–590.
† Berliner Klinische Wochenschrift, No. 38, 1864, p. 369.
‡ De l'Emploi de la Fève de Calabar dans le Traitment du Tetanus Paris, 1867.

preliminary note was published, and have since greatly extended.* The observations of another experimenter, Professor BARTHOLOW, of Cincinnati, have likewise only recently come to my knowledge. The publication, in the "Practitioner" of February 1870, of a paper by me on "Atropia as a Physiological Antidote to the Poisonous Action of Physostigma," directed Dr BARTHOLOW's attention to my researches, and by his courtesy and kindness I have been favoured with a copy of an essay on "Atropia," which he had published in 1869. I am thereby enabled to supply an omission that would otherwise have occurred in this account of the literature of the subject, for the essay contains not only an interesting theoretical discussion on the antagonism between atropia and physostigma, but also several experiments bearing on its existence. The experiments were performed on frogs and cats, and a description is given of two experiments on each of these species of animal. One experiment on a frog and one on a cat terminated in recovery, while the two others terminated in death. From these experiments Dr BARTHOLOW deduces a number of general conclusions regarding the mutual counteraction of the two substances on several of the structures and functions modified by them. The following quotation contains an epitome of his views :—"Atropia is not a physiological antagonist to physostigma, except in regard to their action on the organic nervous system. It would be improper, then, to use atropia against poisoning by Calabar bean. . ."† The second of these propositions seems to imply that the existence of a lethal antagonism was not favoured by the results of the experiments. The account given of the experiments, however, does not justify any opinion as to how far the non-existence of a lethal antagonism is supported by them, for, unfortunately, the obviously necessary information is omitted by which to judge if a lethal dose of one or other substance had been administered to either of the animals that recovered.

Preparations used in the Research.—In this research physostigma was administered in the form either of an alcoholic extract, or of the sulphate of the active principle.

The alcoholic extract was prepared by placing a moderately fine powder of the kernel in a percolator, acting upon it with alcohol (84 per cent.) until the powder was exhausted, and then concentrating the tincture by distillation and by evaporation on a water bath, until an extract of ordinary consistence was

* Since this sentence was written, I have received a more recent paper by M. BOURNEVILLE, which contains evidence of an absolutely satisfactory nature regarding the power of atropia to counteract the lethal action of physostigma. It is entitled, "De l'Antagonisme de la Fève de Calabar et de l'Atropine," and appears to be a reprint from the "Revue Photographique des Hôpitaux," of June 1870. A description is given of five experiments on guinea pigs, in which non-lethal doses of atropia were administered a few minutes after lethal doses of extract of physostigma, with the result that recovery took place in all of the experiments. The great value of the evidence contained in this paper depends on the fact that the doses of physostigma given were proved to be at least equal to the minimum lethal. This was accomplished in much the same way as has been described in my preliminary note in the Proceedings of this Society, and in my communication to the "Practitioner" of February 1870.

† *Loc. cit.* p. 46.

obtained. This preparation contains a considerable quantity of fatty matter, which prevents its complete solution in water; and as the division into separate doses of a mere watery suspension would lead to many inaccuracies, it was found necessary to weigh the requisite quantity separately for each experiment. It is also hygroscopic, which further required that it should be dried and kept in an exsiccator, in order to ensure an unvarying preparation. Nearly all the experiments in which an extract was used were made with one prepared in this manner, and a sufficient quantity was obtained by one process to serve for the entire research. A few experiments, however, were made with an extract for which I am indebted to Dr Cook, of the firm of Messrs T. and H. Smith, of Edinburgh. It will be seen, from the description of these experiments, that Dr Cook's extract is more powerful than that prepared by myself, and this may be accounted for by the fact that absolute alcohol was employed in its preparation.

The active principle, physostigmia,* whose sulphate was also used in this research, was obtained by the following process. Alcoholic extract of physostigma was mixed with distilled water, and the fatty matters were completely removed by agitation with successive portions of sulphuric ether. An excess of bicarbonate of sodium was then added to the watery solution, and the resulting alkaline liquor was shaken with successive portions of ether. The decanted etherial solutions were washed with water, concentrated by distillation, and then evaporated spontaneously, by which means a residue consisting of an impure physostigmia was obtained. This was dried over sulphuric acid, and treated with anhydrous ether, and on evaporating the etherial solution, a less impure physostigmia was obtained in the form of a pale brown extract-like substance. From it the sulphate was prepared by neutralising a solution in rectified spirit with very dilute sulphuric acid, and evaporating at a low temperature. This sulphate is a pale brown amorphous substance, readily soluble in distilled water. As watery solutions of the vegetable alkaloids gradually undergo decomposition, it was considered advisable to weigh separately the dose required for each experiment. Physostigmia, in common with the extract, possesses the inconvenient property of absorbing moisture from the atmosphere, and for this reason, the obviously necessary precaution was adopted of keeping the sulphate in an exsiccator.

The atropia was administered in the form of sulphate, which salt was purchased from Messrs T. and H. Smith of this city. The doses were generally

* This alkaloid was first separated by me in 1863; and in a paper published in 1864 ("On the Moth of the Eserĕ, or Ordeal Bean of Old Calabar," Annals and Magazine of Natural History, May, 1864), I named it *Eserinia*, from Eserĕ, the usual name of the ordeal poison at Calabar. Since then I have, in various publications, adhered to this name, and it has been almost invariably adopted by French physiologists and chemists. The reasons in favour of designating an active principle, derived from the vegetable kingdom, by a modification of the generic name of its botanical source are, however, so numerous and weighty, that I have thought it right in the present communication to follow the usual practice. This I have the more readily done, as the name physostigmia (or physostigmin) is now commonly to be met with in the writings of German physiologists.

weighed separately for each experiment, but in several instances it was found necessary to subdivide a recently prepared solution, as such minute doses were required that it would have been impossible to weigh them accurately.

Subjects of Experiment.—With a few exceptions, wherein dogs were used, the experiments were performed on rabbits. The animals were invariably in a state of perfect health, and in full digestion. The latter is a condition of great importance, the plan of research requiring a strict attention to the relation between the weight of the animal and the doses of the substances. The amount of food contained in the stomach appreciably modifies the weight both of dogs and rabbits, but it does so to a very marked extent in rabbits, for on several occasions I have found that an increase of three or four ounces occurred after food had been taken. As, generally, the rabbits employed were about three pounds in weight, the difference represented by such an increase is obviously of importance in estimating the doses of the substances.

Plan of Experiments.—The following plan was adopted for the experiments, as it appeared to be the one by which the most conclusive results were to be obtained :—In the first place, the minimum fatal dose for rabbits of the extract of physostigma and of the sulphate of physostigmia employed was determined by a number of preliminary experiments, so that, on the weight of the animal being ascertained it was an easy matter to be certain of the dose that could kill it. Then, in those experiments in which recovery followed the administration of a dose of atropia given in combination with a dose of physostigma equal to or in excess of the minimum fatal, the animal used was killed many days afterwards, and when the effects of the two substances had completely disappeared, by a dose of physostigma less than or only equal to that from which it had previously recovered. *Therefore, when the administration of atropia prevented an otherwise fatal dose of physostigma from causing death, a perfect demonstration was obtained of the power of atropia to produce some physiological action or actions that counteracted some otherwise lethal action or actions of physostigma.*

The administration of the substances was effected by subcutaneous injection. There is an abundance of evidence to show that, when exhibited by subcutaneous injection, the activity of a substance, relatively to its dose, is considerably greater than when it is exhibited by introduction into the stomach. By adopting this method, therefore, the existence of a lethal antagonism was subjected to a more severe test than if the substances had been introduced into the stomach ; for, not only are the general physiological effects produced with greater rapidity and certainty, but also the lethal action of a minimum fatal dose is induced in a shorter time when the substances are injected under the skin than when they are introduced into the stomach. This method of administration has, besides, the great recommendation of being followed by results constant as to both character and time of occurrence ; for not only is the total quantity, within cer-

tain limits, of the substance absorbed into the blood, but also the process of absorption is commenced directly after the injection is effected. Further, it has the great advantage of convenience, wherein it is greatly superior to the method by introduction into the stomach.

Chief Objects of the Research.—As evidence was obtained at an early period in this research of the existence of an antagonism between the general actions of physostigma and atropia, a wide field for further investigation was thereby opened up. In the experiments that will be described in the first portion of this communication, I shall endeavour to show, as clearly as possible, that atropia possesses, in a remarkable degree, the power of counteracting the lethal action of physostigma. In the subsequent portion of the communication the extent of this power will be examined and its limits defined.

Section A.—Examination of the Influence of Atropia upon the Lethal Activity of Physostigma.

Determination of the Minimum Lethal Doses of the Preparations.

In accordance with the plan that has been adopted for this research, several preliminary experiments were made in order to determine the minimum lethal dose for rabbits of each of the preparations employed. For the present purpose it is sufficient to mention only the leading results of these experiments.

Minimum Lethal Dose of Sulphate of Atropia.—In the following table a summary is given of experiments undertaken to determine the minimum lethal dose for rabbits of sulphate of atropia.

Number of Experiment.	Weight of Rabbit.	Actual Dose.	Dose per 3 lbs. Weight of Animal.	Result.	Notes.
1.	4 lbs. 13 oz.	4 grs.	2·49 grs.	Recovery.	The only effects were dilatation of the pupils, slight restlessness, and acceleration of the cardiac contractions and of the respirations.
2.	4 lbs. 10 oz.	5 grs.	3·24 grs.	Recovery.	Do.
3.	4 lbs. 8 oz.	9 grs.	6 grs.	Recovery.	Do. Also some obvious symptoms of visual derangement.
4.	3 lbs.	6·5 grs.	6·5 grs.	Recovery.	Distinct, though unimportant, paralytic symptoms were produced, the respirations were reduced in frequency, the cardiac action was accelerated, and the pupils were dilated.
5.	3 lbs. 5 oz.	7·9 grs.	7·5 grs.	Recovery.	Do.

Number of Experiment.	Weight of Rabbit.	Actual Dose.	Dose per 3 lbs. Weight of Animal.	Result.	Notes.
6.	2 lbs. 15 oz.	7·34 grs.	7·5 grs.	Recovery.	Do.; excepting reduction in the frequency of the respirations.
7.	2 lbs. 4 oz.	6 grs.	8 grs.	Recovery.	Do. do.; and production of hypnosis.
8.	3 lbs.	9 grs.	9 grs.	Recovery.	Dilatation of the pupils, increase in the frequency of the cardiac and respiratory movements, and slight paralysis were produced.
9.	3 lbs. 2 oz.	15·6 grs.	15 grs.	Recovery.	Dilatation of the pupils, acceleration of the heart's action, increase followed by reduction in the rate of the respirations, distinct paralysis, and tremors and starts, were produced.
10.	2 lbs. 12 oz.	16·5 grs.	18 grs.	Recovery.	Do.
11.	3 lbs.	19·5 grs.	19·5 grs.	Recovery.	The chief effects were dilatation (not extreme) of the pupils, acceleration followed by slowing and weakening of the heart's action; reduction in the rate of the respirations; hypnosis; and well-marked paralysis.
12.	2 lbs. 13 oz.	19·9 grs.	21 grs.	Death, in more than 1 hour, and less than 5 hours 30 minutes.	Do.
13.	2 lbs. 13½ oz.	19·9 grs.	21 grs.	Recovery.	Do.
14.	3 lbs. 2 oz.	23·43 grs.	22·5 grs.	Recovery.	Do.
15.	3 lbs. 1½ oz.	22·9 grs.	22·5 grs.	Recovery.	Do.
16.	3 lbs. 6 oz.	27 grs.	24 grs.	Death in 35 minutes.	The chief effects were dilatation (not extreme) of the pupils; acceleration soon followed by slowing and great weakening of the heart's action; reduction in the rate and strength of the respirations; paralysis; and feeble tremors and spasms.

In each of these experiments every precaution was taken to prevent fallacy It will, however, be observed, that while, in one case, a dose of 21 grains, and in another one of 24 grains per three pounds weight, was found sufficient to cause

death, in two other cases recovery followed the administration of 22·5 and of 21 grains respectively. It must, therefore, be allowed that the minimum fatal dose has only approximatively been determined. A more accurate determination could not be effected without greatly increasing the number of experiments. Fortunately, however, it was unnecessary to incur the trouble and expense* that would thereby have been entailed, as an approximative determination of the minimum fatal dose of atropia was all that was needed for the purpose of this research.†

Minimum Lethal Dose of Extract of Physostigma.—The experiments which are mentioned in the next table were undertaken to determine the minimum lethal dose for rabbits of extract of physostigma.

Number of Experiment.	Weight of Rabbit.	Actual Dose.	Dose per 3 lbs. Weight of Animal.	Result.
17.	3 lbs. 3 oz.	0·8 gr.	0·7 gr.	Recovery.
18.	3 lbs.	0·9 gr.	0·9 gr.	Recovery.
19.	3 lbs. 2 oz.	0·93 gr.	0·9 gr.	Recovery.
20.	3 lbs. 8 oz.	1·2 gr.	1·02 gr.	Recovery.
21.	3 lbs. 6 oz.	1·18 gr.	1·05 gr.	Recovery.
22.	2 lbs. 14 oz.	1 gr.	1·05 gr.	Recovery.
23.	3 lbs. 1 oz.	1·2 gr.	1·2 gr.	Death, in about 27 minutes.
24.	3 lbs. 6 oz.	1·35 gr.	1·2 gr.	Death, in about 23 minutes.
25.	3 lbs. 5 oz.	1·32 gr.	1·2 gr.	Death, in about 33 minutes.
26.	3 lbs. 2 oz.	1·87 gr.	1·8 gr.	Death, in about 16 minutes.

The results of these experiments indicate that the minimum lethal dose for rabbits of extract of physostigma is 1·2 grain for every three pounds weight of animal, or 0·4 grain for every pound.

Minimum Lethal Dose of Sulphate of Physostigmia.—The minimum lethal dose for rabbits of sulphate of physostigmia was discovered by the experiments that are epitomised in the next table.

* The price of sulphate of atropia being a little more than fifteen shillings for sixty grains, the question of expense becomes worthy of consideration.

† The minimum lethal dose of sulphate of atropia, administered subcutaneously, appears to be smaller for dogs than for rabbits. Among other experiments, I have performed the following :—A dog, weighing seven pounds and fifteen ounces, received twenty grains, and recovery followed; but when a dose of twenty-five grains was given to the same dog, eight days subsequently, death occurred in twenty-three minutes. Another dog, weighing sixteen pounds, which, seven days previously, had recovered after the administration of ten grains, died on the fourth day after it had received fifteen grains.

Number of Experiment.	Weight of Rabbit.	Actual Dose.	Dose per 3 lbs. Weight of Animal.	Result.
27.	3 lbs. 8 oz.	0·035 gr.	0·03 gr.	Recovery.
28.	3 lbs. 1 oz.	0·076 gr.	0·075 gr.	Recovery.
29.	3 lbs. 11 oz.	0·1 gr.	0·081 gr.	Death, in about 33 minutes.
30.	3 lbs. 2 oz.	0·1 gr.	0·096 gr.	Recovery.
31.	3 lbs. 1 oz.	0·12 gr.	0·117 gr.	Death, in about 37 minutes.
32.	3 lbs. 5 oz.	0·13 gr.	0·117 gr.	Death, in about 44 minutes.
33.	3 lbs. 4 oz.	0·13 gr.	0·12 gr.	Death, in about 34 minutes.
34.	2 lbs. 14 oz.	0·13 gr.	0·13 gr.	Death, in about 22 minutes.
35.	3 lbs. 6 oz.	0·15 gr.	0·13 gr.	Death, in about 16 minutes.
36.	3 lbs. 4 oz.	0·16 gr.	0·147 gr.	Death, in about 25 minutes.
37.	3 lbs.	0·15 gr.	0·15 gr.	Death, in about 28 minutes.
38.	3 lbs. 3 oz.	0·16 gr.	0·15 gr.	Death, in about 21 minutes.
39.	3 lbs. 2 oz.	0·19 gr.	0·18 gr.	Death, in about 16 minutes.
40.	3 lbs. 1 oz.	0·18 gr.	0·18 gr.	Death, in about 19 minutes.

From these experiments, it would appear that in rabbits the minimum lethal dose of sulphate of physostigmia is a little less than 0·12 grain for every three pounds weight of animal, or 0·04 grain for every pound. The experiment in which death occurred after the administration of 0·08 grain per three pounds weight (Expt. 29), must be regarded as an exceptional one, seeing that during it the rabbit was in a violently excited state; and the constant energetic movements that were made placed the animal in an unfavourable condition to resist the toxic influence of a poison that materially embarrasses both the cardiac and the respiratory functions. Still, even after excepting this experiment, the table shows that 0·12 grain per three pounds is a dose rather in excess of the minimum fatal. I have, however, adopted it as the minimum fatal dose; and the ratio of one to ten that is thereby obtained between corresponding lethal doses of sulphate of physostigmia and extract of physostigma is a very convenient one, and greatly facilitates the substitution of the one substance for the other in doses credited with equal lethal activity.

It may not be altogether unnecessary to point out that the results of these determinations are applicable only to the special preparations with which they have been obtained; for the composition, and therefore the lethal activity, of each of them varies somewhat in accordance with the processes followed in its manufacture.

Influence of Atropia on the Lethal Action of Physostigma.

The minimum fatal dose for rabbits of the extract of physostigma and of the sulphate of physostigmia having thus, with considerable accuracy, been determined, the influence of atropia on the lethal action of physostigma formed the next subject of examination.

Atropia administered before Physostigma.—The nature of this influence when atropia is administered before physostigma is shown by the following experiments :—

EXPERIMENT **41-a.**—In a rabbit weighing two pounds and fifteen and a half ounces, it was found that the number of the cardiac impulses was 40 in ten seconds, and of the respirations 12 in ten seconds, and that the pupils measured $\frac{14}{50}$ths × $\frac{13}{50}$ths of an inch.

Three-tenths of a grain of sulphate of atropia, dissolved in 30 minims of distilled water, was injected under the skin of the left flank. In two minutes and thirty seconds thereafter, the pupils measured $\frac{16}{50}$ths × $\frac{16}{50}$ths of an inch ; and in four minutes, the cardiac impulse occurred 54 times in ten seconds.

Five minutes after the injection of sulphate of atropia, one grain and a fifth of extract of physostigma, suspended in 25 minims of distilled water, was injected under the skin at the right flank ; and, immediately afterwards, the syringe was washed out with 15 minims of distilled water, and this solution injected under the skin at the right hip—the whole operation lasting thirty seconds.

In two minutes after the total dose of physostigma had been injected, the pupils measured $\frac{17}{50}$ths × $\frac{17}{50}$ths of an inch, and infrequent fibrillary twitches were occurring at the right flank and hip. In nine minutes, the rabbit became restless, having been perfectly quiet until now, and the pupils measured $\frac{18}{50}$ths by $\frac{18}{50}$ths of an inch. Soon afterwards, fibrillary twitches were occurring generally over the surface of the rabbit, some unsteadiness was apparent in the movements, and often slight tremblings took place, especially marked in the head. In fifteen minutes, the fibrillary twitchings were more frequent and more strongly marked, so that it was difficult to distinguish the cardiac impulse, but it appeared to occur about 46 times in the ten seconds. In twenty-six minutes, the general symptoms had become slightly aggravated, as a normal posture was maintained only with difficulty ; the arching of the back becoming gradually less prominent, and the head drooping a little. At the same time the fibrillary twitches had become more marked, so that the skin of the whole surface of the animal was in constant movement, and occasionally a weak spasmodic start occurred. In thirty-seven minutes, the head had so far subsided as to permit the chin to rest on the floor, but this latter posture was maintained for only a few minutes, and was succeeded by a more natural one in which the head was raised. In fifty-seven minutes, the rabbit was in a normal sitting attitude, and the chief symptom was well marked universal fibrillary twitching. The pupils measured $\frac{16}{50}$ths × $\frac{16}{50}$ths of an inch, the cardiac impulse was at the rate of 41 in the ten seconds, and the respirations 16 in the ten seconds. In one hour some urine was voided, and three minutes afterwards a considerable quantity of pultaceous and wet fæces was passed. In one hour and sixteen minutes, slight mucous sounds, apparently originating in the larynx, were heard during the respirations, and fæces having the unnatural appearance above described

were again passed. In one hour and thirty minutes, the rabbit was still in the normal sitting posture it had for some time assumed, and when it was obliged to move about no obvious difficulty could be detected. The fibrillary twitches had decreased considerably; the rate of the cardiac impulse was 40 in ten seconds; and the pupils measured $\frac{16}{50}$ths × $\frac{16}{50}$ths of an inch.

On the following day, twenty-three hours after the commencement of the experiment, the rabbit appeared to be perfectly well, for it went about actively and fed well. The rate of the cardiac impulse was 52, and that of the respirations 12 in ten seconds, and the pupils measured $\frac{16}{50}$ths × $\frac{16}{50}$ths of an inch. From this time, a gradual diminution went on in the rapidity of the heart's action, and in the size of the pupil; until, on the fifth day, the former had assumed the normal rate of 41 in ten seconds, and the latter measured exactly the same as before the experiment was commenced, namely, $\frac{14}{50}$ths × $\frac{13}{50}$ths of an inch.

On the eleventh day this rabbit was subjected to the influence of a minimum lethal dose of extract of physostigma, and the result is described in the next experiment. It is of importance to note, that during all this time food had been supplied to the rabbit *ad libitum*, as this is of importance in the maintenance of a state of absolute health, and that the same was also done in all the similar experiments of this research.

Experiment **41-b.**—This rabbit now weighed three pounds, and it was ascertained that in ten seconds the cardiac impulse occurred 41 times, and the respiratory movements 17 times, and that the pupils measured $\frac{14}{50}$ths × $\frac{13}{50}$ths of an inch.

One grain and a fifth of extract of physostigma, suspended in 25 minims of distilled water, was injected under the skin at the right flank, and the syringe washings under that at the right hip. The first effect observed was the occurrence of infrequent and slight twitchings of the *panniculus carnosus* muscle in the neighbourhood of the regions where the injections had been made, and this effect commenced in about one minute and thirty seconds after the first of the two injections. Beyond this, there was no obvious symptom until six minutes, when some slightly restless general movements were made, and at the same time movements of the mouth and lips occurred, as if an accumulation of saliva were being removed. Soon afterwards, there was evident difficulty in going about; gradually slight stiffness showed itself in the anterior, and then in the posterior extremities, which by-and-by became extended, and thereafter the rabbit stumbled about, or stood shaking with the body elevated on the extended limbs. In eight minutes, the above condition was present, and besides, the fibrillary twitchings had become more general and frequent, and the pupils slightly larger, having increased from $\frac{14}{50}$ths × $\frac{13}{50}$ths to $\frac{15}{50}$ths × $\frac{14}{50}$ths of an inch. In ten minutes, the extended state of the limbs disappeared, and was succeeded by partial paralysis, so that the rabbit now sank down on the abdomen and chest. In thirteen minutes, great general weakness, accompanied with constant

tremblings, was present, now and then somewhat severe tremors occurred, fluid (salivary) was escaping from the mouth, soft and pultaceous fæces, wet on the surface, but preserving the pellet shape, were being passed, and the pupils measured $\frac{1}{5}\frac{3}{0}$ths × $\frac{1}{5}\frac{2}{0}$ths of an inch. In fourteen minutes, the respiratory movements were somewhat embarrassed, and accompanied with moist sounds, while their frequency was diminished to about 10 in ten seconds. The head of the animal was now lying on the table, the back was scarcely at all curved, but the general tremors had almost disappeared, although the fibrillary twitchings had rather increased in frequency. In seventeen minutes, the rabbit fell over on the side. Only slight fibrillary twitchings were now present; the respirations were laboured, greatly impeded by mucus accumulated in the mouth and larynx, and accompanied with struggling movements of the body and limbs; the pupils measured $\frac{1}{5}\frac{1}{0}$ths × $\frac{1}{5}\frac{1}{0}$ths of an inch; the cardiac impulse was weak and infrequent; frothy saliva was escaping from the mouth, and liquid fæces were being passed at intervals. Very soon afterwards, the respiratory movements became mere laboured gasps, the pupils still further diminished in size, and general weak tremors succeeded each other. By-and-by it was a matter of difficulty to distinguish any respiratory movement or cardiac impulse, and then, at twenty-two minutes after the administration of the poison, death occurred.

After death, fibrillary twitchings continued for more than twenty minutes, and the first appearance of rigor was seen in thirty minutes, the extremities having then become slightly stiff (temperature of laboratory, 63° F.). The *post mortem* changes in the condition of the pupils were as follows:—at the moment of death, they dilated to $\frac{1}{5}\frac{3}{0}$ths × $\frac{1}{5}\frac{3}{0}$ths of an inch; in one minute, they had contracted to $\frac{1}{5}\frac{2}{0}$ths × $\frac{1}{5}\frac{2}{0}$ths; in two minutes, to $\frac{1}{5}\frac{1}{0}$ths × $\frac{1}{5}\frac{0}{0}$ths; in three minutes, to $\frac{8}{5}\frac{}{0}$ths × $\frac{7}{5}\frac{}{0}$ths; in four minutes, to $\frac{6}{5}\frac{}{0}$ths × $\frac{5}{5}\frac{}{0}$ths; in six minutes, to $\frac{5}{5}\frac{}{0}$ths × $\frac{4}{5}\frac{}{0}$ths; and they continued at the last size until twenty-four minutes after death, when they became dilated to $\frac{6}{5}\frac{}{0}$ths × $\frac{5}{5}\frac{}{0}$ths. On the following day and while strong general rigor was present, the pupils measured $\frac{1}{5}\frac{0}{0}$ths × $\frac{1}{5}\frac{0}{0}$ths of an inch.

The influence of atropia on the lethal action of a much larger dose of the extract was tested in the next experiment.

Experiment **42-a.**—In a rabbit, weighing three pounds and four ounces, preliminary observations showed that the average rapidity of the heart's action was 42 in ten seconds; and of the respiratory movements, 26 in ten seconds; and that the pupils measured $\frac{1}{5}\frac{4}{0}$ths × $\frac{1}{5}\frac{3}{0}$ths of an inch.

A seventeen-hundredth of a grain of sulphate of atropia, dissolved in 30 minims of distilled water, was injected under the skin at the left flank. Two minutes thereafter, the rate of the heart's action was 50 in ten seconds. In four minutes, it had still further increased, having attained a rate of 54 in ten seconds, while now the respiratory movements occurred 18 times in ten

seconds, and the pupils measured $\frac{16}{50}$ths × $\frac{16}{50}$ths of an inch. With these exceptions, there were no appreciable symptoms present.

Five minutes after the administration of atropia, I injected under the skin at the right flank a mixture of three grains and nine-tenths of a grain of extract of physostigma with 40 minims of distilled water; and, afterwards, under the skin at the right hip, the few drops of distilled water with which the syringe was subsequently washed. In three minutes after the injection of the extract of physostigma, the cardiac impulse occurred 58 times in ten seconds; the pupils measured $\frac{18}{50}$ths × $\frac{18}{50}$ths of an inch, and infrequent and slight twitches were present at the right flank and hip. In five minutes, the animal was somewhat restless, and the heart's rate was now 60 in ten seconds. In seven minutes, the restlessness was accompanied by slight involuntary shaking of the head; and, soon after, a great increase took place in the frequency of the fibrillary twitchings of the *panniculus carnosus* muscle over the whole surface of the body. In ten minutes, some weakness was present in the anterior extremities, and gentle tremors, brief in their continuance, occurred whenever movements were made, or the animal was startled by any cause. The weakness of the anterior extremities soon became so great that they were unable to support the fore part of the body, and then the animal sank down on the abdomen and chest. Several series of tremors followed this change of posture; and, on their termination, the head drooped until the lower jaw was rested on the table. In fifteen minutes, this posture was still unchanged, except that the arching of the back had disappeared. The cardiac impulse occurred 61 times, and the respiratory movements 19 times, in ten seconds, and the pupils measured $\frac{18}{50}$ths × $\frac{18}{50}$ths of an inch. This general condition was maintained unchanged for about fifteen minutes, with the exception of a marked decrease in the frequency of the fibrillary twitchings, and an unimportant diminution in the rate of the respiratory movements. Soon afterwards the symptoms became more serious; for in forty minutes the respiratory movements occurred only thirteen times in ten seconds, and their character was somewhat abnormal; for not only were they weak, and almost entirely confined to the diaphragm and the abdominal muscles, but the expiratory movements were abrupt and slightly spasmodic. This depreciation in the character of the respiratory movements appeared to cause considerable distress, as the animal every now and then raised the head in an uneasy manner, notwithstanding that there seemed to be great difficulty in doing so. At this time the heart's action was at the rate of 57 in ten seconds. These symptoms continued for about one hour and ten minutes, but at the end of this time a slight improvement was manifested; for, in two hours after the injection of physostigma, the respirations had increased in rate to 12 in ten seconds, and had become almost normal in their character. In two hours and thirty minutes, the improved state of the animal

was still further indicated by the head being often kept up, without any trembling, for several seconds, and by the back being again arched; but the limbs were still sprawling helplessly, and no general movement could be accomplished. The cardiac impulse was now found to recur 47 times in ten seconds, and the pupils to measure $\frac{17}{50}$ths × $\frac{17}{50}$ths of an inch, while only rarely a weak twitch in some portion of the *panniculus carnosus* muscle could be detected. The observations were now interrupted until six hours and thirty minutes after the injection of physostigma, by which time a very great improvement had taken place in the condition of the animal. A normal sitting posture had been resumed; paralytic symptoms had almost disappeared, and the rabbit was able to go about without much difficulty; and neither general tremors nor fibrillary twitchings occurred. The rate of the heart's action was 31 in ten seconds; the respirations were irregular, being 20 in one period of ten seconds, and 27 in another; and the pupils measured $\frac{17}{50}$ths × $\frac{17}{50}$ths of an inch. It was seen that in the interval during which no observations were made a large quantity of fæces, having normal characters, had been passed; but no urine had yet been voided.

On the following day, the rabbit was found going about actively, and freely consumed the food that was given to it. The cardiac impulse was at the rate of 27, and the respirations were at that of about 12, in ten seconds; but the latter were very irregular. The pupils measured $\frac{17}{50}$ths × $\frac{17}{50}$ths of an inch.

On the third day, the cardiac impulse was at the rate of 37, and the respirations (now pretty regular), were at that of 24 in ten seconds; and the pupils measured $\frac{15}{50}$ths × $\frac{15}{50}$ths of an inch.

On the fifth day, the cardiac impulse was at the rate of 40, and the respirations were at that of 23, in ten seconds; and the pupils measured $\frac{14}{50}$ths × $\frac{13}{50}$ths of an inch. By this time, therefore, every appreciable effect of the experiment had disappeared.

On the ninth day, a dose of extract, weighing only one-third of that which had been given in this experiment, was administered to the same rabbit; and the results of this administration will now be described.

Experiment **42-b**.—The rabbit now weighed three pounds and five ounces; and immediately before the administration, the rate of the heart's impulse was 42, and that of the respirations 21, in ten seconds. One grain and three-tenths of extract of physostigma was mixed with 20 minims of distilled water, and the mixture injected under the skin at the right flank. The syringe was then washed out with a few drops of distilled water, and the washing in its turn injected under the skin at the right hip. Within one minute and thirty seconds thereafter, faint fibrillary twitchings occurred, at rare intervals, at the right flank. These gradually increased in frequency, until they became a prominent symptom, within four minutes from the commencement of the injection. At this time, the heart's rate had diminished to 33 in ten seconds; but the

respirations still retained their previous frequency. In six minutes, the rate of the heart's impulse was 28, and that of the respirations 21, in ten seconds; the fibrillary twitches had become rather more frequent and marked; and movements of the mouth and lips occurred, which were of such a kind as to suggest that some substance was being moved from the anterior part of the mouth and swallowed. There was no other symptom present, and the rabbit sat quietly on the elevated table on which it had been placed. In eight minutes, however, uneasiness was manifested by some restless movements, which at first were somewhat unsteadily performed, and by-and-by were attended with stumblings and occasional slight tremors. The latter symptoms appeared to be caused by an undue extension rather than by flaccidity of the limbs. In ten minutes, the four limbs were in almost complete extension, and the rabbit either stood unsteadily, or went about stiffly and with stumblings on the limbs thus extended. The pupils measured $\frac{15}{50}$ths × $\frac{15}{50}$ths of an inch; and moist sounds frequently accompanied the slightly accelerated respiratory movements. No marked change occurred in the condition of the rabbit for several minutes; but at fourteen minutes after the injection, the extended state of the anterior extremities had almost entirely disappeared, and the thorax not infrequently rested on the table, while the pelvis and posterior parts of the body were elevated on the still extended posterior extremities. The pupils had now contracted to $\frac{11}{50}$ths × $\frac{11}{50}$ths of an inch, and the heart's rate had decreased to 22 beats in ten seconds. In eighteen minutes, the rabbit lay on the abdomen and chest, with the head drooping, and occasionally resting on the table; the respirations occurred 25 times in ten seconds, and were accompanied with noisy bubbling sounds; frothy saliva was escaping from the mouth; and fæces, of a green colour and semi-liquid consistence, were being passed. Soon, the respiratory movements became laboured, less frequent, and often greatly obstructed by accumulations of frothy fluid in the mouth and air-passages; and the rabbit was extended on the abdomen, with the head resting on the table, from which it was raised, though with difficulty, whenever the respiratory movements were much impeded. In twenty minutes, some general struggling movements occurred, obviously due to obstructed respiration, and the rabbit fell over on the side. The cardiac impulses were now at the rate of 18 in ten seconds; the pupils measured $\frac{6}{50}$ths × $\frac{5}{50}$ths of an inch; and the fibrillary twitchings were very frequent, and affected the whole surface of the animal. The difficulty in the performance of the respiratory movements gradually became greater, until, in twenty-nine minutes, only one very laboured, gasping respiration occurred every ten seconds. Soon afterwards, two or three series of weak tremors affected the animal, and at the termination of the last of these the respirations altogether ceased, and death took place—thirty-one minutes after the commencement of the first injection.

At the moment of death, the pupils measured $\frac{6}{50}$ths × $\frac{5}{50}$ths of an inch; three minutes afterwards, their size had increased to $\frac{7}{50}$ths × $\frac{7}{50}$ths of an inch; and this increase gradually became greater until one hour and thirty minutes, when they measured $\frac{11}{50}$ths × $\frac{11}{50}$ths of an inch.

The first appearance of *post mortem* rigidity was observed at thirty-two minutes after death, and it consisted of a very slight degree of stiffness restricted to the posterior extremities. The rigidity next appeared in the anterior extremities and the neck, and finally it became universal, but not until one hour and fourteen minutes after death. (Temperature of laboratory, 56° F.)

A considerable quantity of opalescent urine was removed from the bladder, and when tested it was found that the opalescence was due to suspended phosphates, and that the urine was perfectly free from albumen.

In the next experiment, in place of extract of physostigma, the sulphate of the active principle was administered.

Experiment **43-a.**—In a rabbit weighing three pounds, it was found that the rate of the heart's impulse was 44, and that of the respirations 15, in ten seconds, and that the pupils measured $\frac{14}{50}$ths × $\frac{13}{50}$ths of an inch.

A solution containing half a grain of sulphate of atropia in 15 minims of distilled water was injected under the skin at the right flank. In one minute afterwards, the rate of the heart's impulse was 47 in ten seconds; in one minute and thirty seconds, the respirations occurred 22 times in ten seconds; in two minutes, the pupils measured $\frac{15}{50}$ths × $\frac{15}{50}$ths of an inch; in three minutes, the rate of the heart's impulse was 53 in ten seconds; in three minutes and thirty seconds, the respirations occurred 21 times in ten seconds; and in four minutes, the rate of the heart's impulse was 55 in ten seconds, while the pupils measured $\frac{16}{50}$ths × $\frac{16}{50}$ths of an inch.

Five minutes after the sulphate of atropia had been injected, a solution containing six twenty-fifths of a grain of sulphate of physostigmia in 25 minims of distilled water was injected under the skin at the right flank, and then the syringe was washed out with a few minims of distilled water, which was injected under the skin at the right hip—the entire operation occupying thirty seconds. The first symptom that followed was the occurrence of infrequent and slight twitches of small portions of the *panniculus carnosus* muscle, in the neighbourhood of the regions where the two last injections were made. These twitches were first observed one minute and twenty seconds after the commencement of these injections of physostigmia, and they gradually extended over the surface of the animal, until in three minutes they had become general. In four minutes, the rate of the heart's impulse was 49, and that of the respirations 21, in ten seconds; and the pupils now measured $\frac{18}{50}$ths × $\frac{18}{50}$ths of an inch. At this time, also, the respiratory movements were often accompanied with a hiccup-like start. In six minutes, the rate of the heart's impulse had

decreased to 42 in ten seconds; and now the rabbit was affected with occasional tremblings, restlessness was present, and the movements were somewhat impeded by a slight degree of extension of the anterior extremities. In eight minutes, urine and fæces were voided, the latter having a perfectly normal appearance, tremors were of frequent occurrence, and the fibrillary twitchings had become greatly exaggerated, the entire surface of the animal being in constant movement. In ten minutes, the extension of the limbs had given place to undue flaccidity, so that they could scarcely support the body; weak general tremors succeeded each other at intervals; the muscles of the neck seemed unable properly to support the head, which often subsided until the lower jaw nearly rested on the table; the respirations occurred 30 times in ten seconds; and the pupils measured $\frac{1}{5}\frac{8}{0}$ths × $\frac{1}{5}\frac{8}{0}$ths of an inch. In seventeen minutes, the animal fell on the abdomen and chest, and remained in this position. Tremors still occurred, though weaker and less frequent than before, and the fibrillary twitching of the *panniculus carnosus* muscle had rather diminished; but it was apparent that similar twitchings were occurring in the deeper muscles. In twenty-two minutes, the lower jaw was rested on the table, and the arching of the back had almost disappeared. Attempts were made to count the heart's impulse, but when the hand was placed on the animal, tremors so severe and continuous were excited that it was impossible to ascertain the rate with accuracy. In twenty-five minutes, the general weakness had still further increased, so that the limbs were extended helplessly at right angles to the body, and the side of the head was resting on the table. The respirations were now 20 in ten seconds, the pupils measured $\frac{1}{5}\frac{8}{0}$ths × $\frac{1}{5}\frac{8}{0}$ths of an inch, and the fibrillary twitches had become less prominently marked. In thirty minutes, a slight improvement was manifested in the condition of the animal, for spontaneous tremors but rarely occurred, nor were they excited in their former severity when the hand was placed on the body. It was therefore possible to count the heart's impulses, which were ascertained to occur 41 times in ten seconds. A general improvement was still more distinctly perceived at forty minutes after the injection of physostigmia, when the head was now and then quietly elevated, and attempts were made to raise the body from the table. The latter were at first unsuccessful, but at forty-nine minutes the rabbit succeeded in rising, and at once assumed a perfectly normal posture. In fifty-two minutes, several fæcal pellets of natural appearance were passed; the heart's impulse was at the rate of 36, and the respirations were at that of 22, in ten seconds; the fibrillary twitchings were pretty well marked; and the rabbit was able to go about, though with considerable difficulty. After this, the animal usually sat quiet in a normal attitude, and in a short time it was able to go about without any perceptible difficulty. In one hour and thirty minutes, a great number of large fæcal pellets were passed, which were of a somewhat pultaceous consistence. At this time, the rate of

the heart's impulse was 36, and that of the respirations 19, in ten seconds; the pupils measured $\frac{17}{50}$ths × $\frac{17}{50}$ths of an inch, and distinct fibrillary twitchings were still present; with these exceptions, the animal was in a perfectly normal state.

On the following day—at twenty-six hours after the injection of physostigmia—the rabbit was active and well; and it was observed that, since the last note, a considerable quantity of pultaceous fæces had been passed. The rate of the heart's impulse was 32, and that of the respirations 15, in ten seconds; and the pupils measured $\frac{17}{50}$ths × $\frac{17}{50}$ths of an inch.

By the fourth day, a normal rate of the cardiac contractions and respiratory movements, and a normal condition of the pupils, had been reassumed.

On the tenth day, the rabbit was found to weigh three pounds and half an ounce; and it was then made the subject of the following experiment:—

Experiment **43-b.**—Having dissolved six twenty-fifths of a grain of sulphate of physostigmia in 25 minims of distilled water, I injected the solution under the skin at the right flank, and then washed the syringe with a few drops of distilled water, and injected this water under the skin at the right hip. Before this experiment was commenced, the rate of the cardiac impulse was 42, and that of the respirations 19, in ten seconds; and the pupils measured $\frac{14}{50}$ths × $\frac{13}{50}$ths of an inch.

In one minute and thirty seconds after the commencement of the administration, rare fibrillary twitches occurred near the regions of injection; but no marked general symptoms appeared until four minutes and forty seconds, when the limbs, especially the two anterior, became extended. The animal then went about unsteadily, and with considerable difficulty; and the rate of the cardiac impulses was 37 in ten seconds. In six minutes, some fæcal pellets were passed; tremors occurred almost without intermission; stumbling and somewhat excited movements were made; and the extended state of the limbs disappeared, and the rabbit subsided on the abdomen and chest. These symptoms rapidly became more and more serious; the pupils contracted to $\frac{7}{50}$ths × $\frac{6}{50}$ths of an inch; general paralysis became well marked; frequently-recurring tremors, weaker now than before, impeded the respiratory movements, and saliva escaped from the mouth. In eight minutes, the respirations consisted of mere gasps, laboured in their character, and greatly obstructed by mucus, while the rate of the cardiac impulses had become diminished to 13 in ten seconds. Soon afterwards, only rarely-occurring gasps were observed, and it was impossible to detect any cardiac impulse. The former ceased on the occurrence of death, nine minutes and fifty seconds after the commencement of the injection.

At the moment of death, the pupils measured $\frac{5}{50}$ths × $\frac{4}{50}$ths of an inch, and they slowly increased in size until, at forty-one minutes after death, they

measured $\frac{1}{5}\frac{0}{0}$ths × $\frac{9}{5}\frac{0}{0}$ths of an inch; and now, for the first time, *post mortem* rigidity had been initiated, slight stiffness being present in the posterior extremities (temperature of laboratory, 58° F.)

It is very obviously shown by these experiments that the fatal action of certain lethal doses of extract of physostigma, and sulphate of physostigmia, may be prevented in rabbits by the previous administration of atropia.

Atropia and Physostigma simultaneously administered.—In the two following experiments, extract of physostigma and sulphate of atropia were administered simultaneously, or nearly so, only an unavoidable interval of a few seconds intervening between the administration of the two substances.

Experiment **44**-a.—In a rabbit that weighed three pounds and twelve ounces, I injected under the skin of the left flank half a grain of sulphate of atropia, dissolved in 15 minims of distilled water, and immediately afterwards three grains of extract of physostigma, suspended in 28 minims of distilled water. Without any loss of time, the two syringes employed in these injections were washed out with a few drops of distilled water, and the washings were separately injected under the skin at different regions.

Except dilatation of the pupils and fibrillary twitches of the muscular structure beneath the skin, obvious symptoms were but slowly produced, and it was not until eleven minutes after the injections had been finished that paralytic effects were produced. These effects, however, increased in severity somewhat quickly, and in fifteen minutes the rabbit fell over on the side, though it soon turned again, and lay on the abdomen and chest with the back well arched. At this time, the pupils were in full dilatation, fibrillary twitches occurred over the whole surface of the animal, and fæces of normal consistence and colour were passed, while now and again a spasmodic contraction of the abdominal muscles accompanied the inspiratory movements. Unsuccessful efforts were frequently made to raise the body on the limbs, and often resulted in the production of general tremors, during which the rabbit several times fell over on the side. This state of great muscular weakness, attended with well marked fibrillary twitches of the *panniculus carnosus* muscle, and apparently also of muscles more deeply situated, continued, without any improvement, until one hour and ten minutes after the commencement of the experiment, when further observations were interrupted.

On the following day the general state of the rabbit appeared a perfectly normal one. The pupils were, however, in full dilatation, and it was observed that a large quantity of semi-liquid fæces had been passed.

On the third day the fæces that were passed were in every respect normal. Dilatation of the pupils was still present, and this, the most persistent of the symptoms, did not disappear until the sixth day.

On the tenth day, the following experiment was performed; the rabbit

being perfectly well, and weighing three pounds and twelve ounces and a half.

Experiment **44-b.**—I injected one grain and a half of extract of physostigma, suspended in 15 minims of distilled water, under the skin at the right flank, and immediately afterwards washed out the syringe and injected the washings under the skin at the right hip. Effects were produced in every essential character analogous to those that have been described as occurring in the preceding experiments with the extract, and in fifteen minutes the animal was lying on the abdomen and chest. At this time the only noteworthy symptoms were an unusually abundant escape of saliva from the mouth, and a remarkable frequency in the voiding of pultaceous fæces. In twenty-three minutes the rabbit fell over on the side, and while it remained in this position the respirations were laboured and greatly obstructed by mucus accumulated in the larynx and air passages, the pupils were contracted, and the cardiac impulses of infrequent occurrence. In twenty-five minutes a marked improvement occurred in the general condition of the rabbit; it turned so as to rest on the abdomen and chest, the head was frequently raised, and the respirations became more frequent and almost free from obstruction. This improvement was, however, of but short duration, for in forty minutes the respirations again became embarrassed, tremors and irregular and somewhat energetic general movements occurred, and the rabbit again fell over on the side. Gradually the respiratory movements became less frequent, frothy saliva escaped from the mouth and accumulated in the larynx, the pupils diminished in size, and the heart's impulses became feeble and infrequent. Soon afterwards the respirations assumed the character of laboured gasps, greatly impeded by an abundant accumulation of frothy mucus, and they finally ceased at fifty-four minutes after the injection of the extract.

Experiment **45-a.**—In a young rabbit weighing two pounds and eight ounces, I injected half a grain of sulphate of atropia, dissolved in 15 minims of distilled water, under the skin at the right flank, and then one grain of extract of physostigma, suspended in 15 minims of water, under the skin at the left flank. Immediately afterwards the water used in washing out each of the syringes was injected under separate parts of the skin.

Before the experiment the pupils measured $\frac{12}{50}$ths × $\frac{11}{50}$ths of an inch, and in two minutes after the commencement of the first injection they had enlarged to $\frac{15}{50}$ths × $\frac{15}{50}$ths of an inch, while slight fibrillary twitches were observed at the right side in the immediate neighbourhood of the regions where physostigma had been injected. In seven minutes the rabbit became restless; in thirteen minutes the pupils had still further enlarged to $\frac{16}{50}$ths × $\frac{16}{50}$ths of an inch; and in fourteen minutes several fæcal pellets were passed, and the fibrillary twitches were more marked, and occurred over the whole surface of

the animal. With these exceptions, the rabbit appeared to be in a normal state, until eighteen minutes after the commencement of the injections, when symptoms of loss of power occurred in the thoracic extremities; but these symptoms did not become severe until twenty-five minutes, when stumbling movements were made, and soon after the rabbit subsided on to the abdomen and chest. It remained quietly in this attitude, with the head normally raised, for about eight minutes, and then rose up and stood or went about somewhat unsteadily. A large additional quantity of fæces having a normal character was passed, and some urine voided. Soon afterwards the partial paralysis was recovered from, and at forty-five minutes there were no marked general symptoms present, except a dilated state of the pupils and fibrillary twitches. A perfect recovery ultimately occurred.

Thirteen days afterwards the following experiment was performed on this rabbit, which then weighed two pounds and nine ounces.

Experiment **45-b.**—One grain of extract of physostigma, mixed with 15 minims of distilled water, was injected under the skin at the right flank, and immediately afterwards the syringe was washed out with a few drops of distilled water, and this too was injected under the skin.

The phenomena usually produced by such a dose occurred in their ordinary sequence: fibrillary twitches, stiff extension of the limbs succeeded by their partial paralysis, slight tremors, unimportant and transient dilatation followed by marked contraction of the pupils, defæcation, excessive flow of saliva, and then a state of general flaccidity, interrupted now and then by laboured and gasping respirations. In eighteen minutes after the injection of the extract the rabbit was dead.*

Physostigma administered before Atropia.—It is evident, therefore, that atropia is able to prevent the occurrence of death after lethal doses of physostigma, if the two substances be simultaneously administered. The influence that it exerts on the lethal action of physostigma when administered after the dose of this substance is shown by the following experiments. In the first of these, the extract of physostigma was employed.

Experiment **46-a.**—Having ascertained, in a rabbit weighing three pounds and two ounces, that the average rate of the cardiac contractions was 40, and

* As has been frequently noticed in similar experiments, the bladder of this rabbit contained a large quantity of urine. I endeavoured to ascertain whether physostigma is excreted by the kidneys, by the following process:—About two ounces of this urine was evaporated at a low temperature on a water bath, and the residue carefully mixed with a little rectified spirit, and the mixture was then filtered, and in its turn evaporated to dryness at a low temperature. Then the extract thus obtained was triturated with a very little distilled water, and a drop of the resulting fluid was applied to the right eyeball of a rabbit, it having been previously ascertained that both pupils measured $\frac{1}{6}\frac{5}{0}$ths × $\frac{1}{6}\frac{4}{0}$ths of an inch. The pupils were carefully measured at frequent intervals during the following hour and twenty minutes, and it was found that no change occurred in the size of either. It is therefore highly improbable that the physostigma is excreted by the kidneys.

of the respirations 27, per ten seconds, and that the pupils measured $\frac{10}{50}$ths × $\frac{10}{50}$ths of an inch, I injected two grains and a half of extract of physostigma, suspended in 30 minims of distilled water, under the skin of the right flank, and immediately afterwards the washings of the syringe under the skin at the right hip. Two minutes thereafter, the respirations were at the rate of 28 per ten seconds, and infrequent fibrillary twitches occurred at the right side. The animal became slightly restless and appeared uncomfortable. In four minutes the cardiac impulse was at the rate of 30 in ten seconds, but the pupils were unchanged in size.

Five minutes after the commencement of the physostigma injection, half a grain of sulphate of atropia, dissolved in 15 minims of distilled water, was injected under the skin at the left flank, and the washings of the syringe under the skin at the left hip. In one minute after the injection of atropia, the pupils had increased to the size of $\frac{12}{50}$ths × $\frac{12}{50}$ths of an inch, and movements of the lips and mouth, symptomatic of the action of physostigma, were being made. In two minutes, the rate of the cardiac action had increased to 45 in ten seconds, and the fibrillary muscular twitches had become frequent and general over the whole surface of the rabbit; and in four minutes, the size of the pupils had still further increased to $\frac{17}{50}$ths × $\frac{17}{50}$ths of an inch, while the movements of the lips referred to still continued. In eight minutes, the rabbit was sitting normally, though with some slight shaking, the heart's rate was 51 in ten seconds, and the fibrillary muscular twitches had become greatly exaggerated. It was not until fifteen minutes after the administration of atropia, and therefore twenty minutes after that of physostigma, that distinct symptoms of paralysis manifested themselves, and they consisted of merely a slight yielding of the forelimbs during the movements, and a little drooping of the head. At this time the respirations were at the rate of 22 per ten seconds, and the heart's action was very frequent, though it was impossible to ascertain its rate with accuracy, on account of the incessant recurrence of the fibrillary muscular twitches. These various symptoms continued unchanged until twenty-five minutes after the administration of atropia, when the paralytic symptoms became more marked, for whenever the animal attempted to go about it stumbled, and occasionally even fell on the abdomen. It was seen that the pupils had now diminished in size to $\frac{14}{50}$ths × $\frac{14}{50}$ths of an inch. In forty-five minutes a large quantity of urine was voided; in fifty minutes, the pupils measured $\frac{13}{50}$ths × $\frac{13}{50}$ths of an inch, and normal respiratory movements occurred at the rate of 26 in ten seconds; and in one hour several large and somewhat soft fæcal pellets were passed. There was not, as yet, any decided change in the general state of the animal; stumbling occurred when movements were made, and although a normal sitting posture could be assumed, there was distinct drooping of the head while this posture was being maintained. Now, however,

the fibrillary muscular twitches had somewhat diminished, and accordingly it was possible to ascertain with certainty that the rate of the cardiac contractions was 44 per ten seconds. In one hour and ten minutes a little moisture was seen at the mouth, and soon afterwards moist sounds occasionally accompanied the respiratory movements. It was observed, at this time, that the two pupils had become unequal in size, the right measuring, in full light, $\frac{12}{50}$ths × $\frac{12}{50}$ths, and the left $\frac{14}{50}$ths × $\frac{14}{50}$ths, of an inch. In one hour and fifteen minutes the animal went about quite steadily; there was no drooping of the head; the respirations were frequent and no longer accompanied with moist sounds; the cardiac contractions were at the rate of 35 in ten seconds; and several soft and wet fæcal pellets were passed, and a little urine was voided. The accumulation of mucus in the larynx had not, however, been entirely got rid of; for, every now and then, a curious discordant sound, cough-like in its character, was heard, which was unmistakably caused by an effort to get rid of some soft substance in the larynx. In two hours these sounds had altogether ceased; the rate of the cardiac impulses was 41, that of the respiratory movements 22, per ten seconds; and the size of the right pupil was $\frac{10}{50}$ths × $\frac{10}{50}$ths, and of the left $\frac{13}{50}$ths × $\frac{13}{50}$ths of an inch. But with the exception of infrequently occurring fibrillary twitches, there was no obvious symptom present.

On the following day—twenty-seven hours after the commencement of the experiment—the rabbit seemed to be perfectly well. The cardiac contractions were occurring at the rate of 31, and the respiratory movements at that of 19, in ten seconds; and the pupils were still unequal, the right measuring $\frac{13}{50}$ths × $\frac{13}{50}$ths, and the left $\frac{14}{50}$ths × $\frac{14}{50}$ths of an inch.

On the third day the most notable change that had occurred was in the rate of the cardiac contractions, which had by that time reassumed a normal rate of 41 in ten seconds. It was not, however, until the seventh day, that the pupils had resumed their previous size of $\frac{10}{50}$ths × $\frac{10}{50}$ths of an inch.

On the twelfth day the rabbit was in a state of vigorous health; its weight was three pounds and two ounces and three quarters; the rate of the heart's contractions was 41, and that of the respirations 18, in ten seconds; and the pupils measured $\frac{11}{50}$ths × $\frac{10}{50}$ths of an inch.

Experiment **46-b.**—Two minutes after the last observations had been made, the rabbit received, by subcutaneous injection, two grains and a half of extract of physostigma. In three minutes and thirty seconds the rate of the cardiac impulses had fallen to 36 in ten seconds; the respirations were normal, and there were no general symptoms except infrequent fibrillary twitches and movements of the lips and mouth. In four minutes and forty seconds, however, the limbs became extended; and in seven minutes stumbling movements were made, while a slight increase in the size of the pupils was

observed. In eight minutes a series of tremors occurred, which were frequently repeated until the animal, in nine minutes, sank down on the abdomen and chest. At this time, the rate of the heart's contractions was only 19 in ten seconds, and the respirations were considerably diminished in frequency, and somewhat laboured, obstruction being apparently caused by mucus accumulated in the mouth and throat. Very soon afterwards the embarrassment of the respiratory movements became greater, to such an extent that each respiration was accompanied by energetic struggling movements of the whole body; and in eleven minutes they assumed a gasping character. In eleven minutes and thirty seconds the head was drawn back, and a few slight tremors occurred, after which the rabbit was dead.

The first appearance of rigor, consisting of slight stiffness of the posterior extremities, occurred twenty-four minutes after death (temperature of laboratory, 58° F.).

I shall now describe, but with less minuteness, three other experiments, where the administration of atropia was preceded by the administration of a lethal dose of extract of physostigma, and where the interval of time separating the administration of the two substances was greater than in the last experiment.

Experiment **47-a.**—Two grains of extract of physostigma, previously suspended in 20 minims of distilled water, was injected under the skin at the right flank of a rabbit weighing three pounds and eleven ounces and a half. In eight minutes, the rabbit was lying on the abdomen and chest, saliva was escaping abundantly from the mouth, the pupils were somewhat contracted, the respirations were noisy and laboured, and moist fæces were being copiously passed.

At eight minutes and thirty seconds, half a grain of sulphate of atropia, dissolved in 15 minims of distilled water, was injected under the skin at the left flank. In four minutes afterwards the pupils were dilated and the flow of saliva and passage of fæces had ceased. In six minutes vigorous efforts were made to rise; but these were not successful until fifteen minutes. In about one hour and twenty minutes, the rabbit was nearly well, though a slight degree of paralysis was still present. In one hour and forty minutes, every obvious symptom had disappeared, except dilatation of the pupils and fibrillary twitches of the muscles.

Experiment **47-b.**—Four days afterwards, this rabbit, while in a perfectly normal condition, received, by subcutaneous injection, one grain and a half of extract of physostigma, suspended in 15 minims of distilled water. Tremors, paralysis, and great increase of the salivary and bronchial mucus secretions, were quickly produced; moist fæces were, by-and-by, evacuated in large quantity; the pupils became contracted; and death occurred fifteen minutes and thirty seconds after the administration.

In the next experiment, an interval of ten minutes and thirty seconds was allowed to intervene between the administration of the two substances.

EXPERIMENT **48-a**.—A young rabbit, weighing two pounds and fourteen ounces, received, by subcutaneous injection, one grain and a half of extract of physostigma, suspended in 15 minims of distilled water. Symptoms of physostigma action appeared in one minute and thirty seconds; but they did not assume a serious aspect until six minutes after the administration, when the rabbit had great difficulty in maintaining a sitting posture. In nine minutes, it fell, and rested on the abdomen, chest, and lower jaw. In ten minutes, fæces were passed, and saliva escaped from the mouth; while the animal lay flaccidly, quite unable to move about, and, every now and then, was affected with tremors.

At ten minutes and thirty seconds, half a grain of sulphate of atropia, dissolved in 15 minims of distilled water, was injected under the skin at the left flank. No obvious result occurred until four minutes and thirty seconds, when the state of flaccidity somewhat lessened, the back becoming normally curved. A few seconds afterwards, the head was again raised, the flow of saliva was considerably diminished, and the pupils were slightly dilated. In eight minutes the rabbit succeeded in rising, and it then sat in a natural posture. At this time, the exaggerated secretion of saliva had become completely checked, and the pupils widely dilated.

EXPERIMENT **48-b**.—Twelve days afterwards, one grain and a fifth of extract of physostigma was suspended in 15 minims of distilled water, and injected under the skin of this rabbit. Death occurred in thirty minutes.

In the following experiment, likewise, extract of physostigma was administered ten minutes and thirty seconds before atropia.

EXPERIMENT **49-a**.—Having suspended one grain and a half of extract of physostigma in 20 minims of distilled water, I injected it under the skin at the right flank of a strong white rabbit, whose weight was three pounds and three ounces. Ten minutes thereafter the rabbit was suffering from an advanced stage of physostigma poisoning. It was lying, unable to make any movements, except irregular struggles; saliva was freely escaping from the mouth; fæces were being passed; the entire surface of the animal was affected with fibrillary twitches; and the pupils were contracted to $\frac{6}{50}$ths × $\frac{5}{50}$ths of an inch, their size before the injection having been $\frac{11}{50}$ths × $\frac{11}{50}$ths of an inch.

At ten minutes and thirty seconds, I injected half a grain of sulphate of atropia, dissolved in 15 minims of distilled water, under the skin at the left flank. In three minutes after the administration of atropia, the pupils measured $\frac{3}{50}$ths × $\frac{2}{50}$ths of an inch, and loud mucous sounds accompanied the respirations. In six minutes, however, a decided improvement occurred, as the rabbit got up and went about, though with considerable difficulty, and in a hurried and excited manner. It was only at rare periods that mucous sounds were heard

with the respirations; the exaggerated flow of saliva ceased; and the pupils became enlarged to $\frac{8}{50}$ths × $\frac{7}{50}$ths of an inch. This improved state gradually became more decided, until at thirty-seven minutes after the injection of atropia, the rabbit seemed to have recovered from every abnormal symptom, except that extremely well-marked fibrillary twitches and dilatation of the pupils to the extent of $\frac{16}{50}$ths × $\frac{16}{50}$ths of an inch were present. At about one hour and thirty minutes, unmistakable symptoms of general physostigma poisoning somewhat unexpectedly again manifested themselves. Fæces, normal at this time in their characters, were passed; the pupils contracted to $\frac{12}{50}$ths × $\frac{12}{50}$ths of an inch, and saliva appeared at the mouth. In one hour and forty minutes, the respirations were constantly accompanied with mucous sounds; soft and, now and again, semi-liquid fæces were passed, and urine was voided; the surface of the eye-balls became unnaturally moist; the pupils measured only $\frac{11}{50}$ths × $\frac{10}{50}$ths of an inch; and the animal lay on the abdomen and chest, apparently unable to go about. However, an improvement in the general condition again occurred at two hours and twenty minutes; and from this time the symptoms became less and less severe, until a perfectly normal condition was established.

Experiment **49–b.**—Nine days afterwards this rabbit, being in a state of vigorous health, and having a weight of three pounds and five ounces, received, by subcutaneous injection, one grain and three-tenths of extract of physostigma. In thirty-four minutes thereafter it was extended on the side; infrequent, laboured, and noisy respiratory gasps were occurring; soft and almost liquid fæces were being passed, along with which there were occasionally some small pieces of a clear jelly-like substance; the cardiac contractions were occurring at a very reduced rate of frequency; and the pupils were in extreme contraction. In forty-six minutes and ten seconds after the administration of physostigma, the rabbit was dead.

In two other experiments that will now be described, physostigmia was administered in the form of sulphate of the active principle, and between the administration of the two substances a period even longer than that in the last experiment intervened.

Experiment **50–a.**—In a rabbit, weighing three pounds and ten ounces, the average rate of the cardiac contractions was found to be 38, and that of the respiratory movements 22, in ten seconds; while the pupils measured $\frac{11}{50}$ths × $\frac{10}{50}$ths of an inch. A solution, containing nine-fifteenths of a grain of sulphate of physostigmia in 20 minims of distilled water, was injected under the skin at the right flank, and, immediately afterwards, the syringe was washed with a few drops of distilled water, and this water was injected under the skin at the right hip. The following symptoms then occurred, the time being computed from the moment when the first injection was commenced:—

	Cardiac Contractions, per 10 seconds.	Respirations, per 10 seconds.	Size of Pupils, in fractions of an inch.	General Symptoms, &c.
In 1 min. 30 sec.	—	19	—	Infrequent fibrillary twitches at right side.
4 „ .	32	14		
6 „ 30 „	29	—	$\frac{1}{5}\frac{2}{0}$ths × $\frac{1}{5}\frac{2}{0}$ths	Movement of lips commenced.
7 „ .	—	—	—	Slight restlessness and some extension of the limbs.
9 „ .	25	16	$\frac{1}{5}\frac{4}{0}$ths × $\frac{1}{5}\frac{4}{0}$ths	The extension of limbs more marked, and some unsteadiness and shaking.
11 „ .	—	—	—	Excited movements, and often stumbles, while series of tremors occur.
12 „ .	—	18	—	Head droops, the stiff extension of the limbs has given place to some flaccidity and weakness, and the fore limbs often give way. Somewhat soft fæces are passed.
14 „ .	14	—	$\frac{1}{5}\frac{1}{0}$ths × $\frac{1}{5}\frac{1}{0}$ths	The respirations are noisy, impeded by mucus, and laboured; and the animal lies on the abdomen and chest. Saliva escapes freely from the mouth.
15 „ .	9	—	$\frac{7}{5}\frac{7}{0}$ths × $\frac{7}{5}\frac{7}{0}$ths	The animal is on the side. Infrequent, laboured, and noisy respirations occur, which are accompanied with general struggles. The cardiac impulse is extremely weak.

At fifteen minutes and ten seconds after the commencement of the injection of sulphate of physostigmia, a solution containing seven-tenths of a grain of sulphate of atropia in ten minims of distilled water was injected under the skin at the back; and immediately afterwards, the syringe was washed and the few minims of water employed was injected under the skin at the right shoulder. After the commencement of these injections of sulphate of atropia, which were made while the animal appeared to be at the point of death, the following symptoms occurred :—

	Cardiac Contractions, per 10 seconds.	Respirations, per 10 seconds.	Size of Pupils, in fractions of an inch.	General Symptoms, &c.
In 1 min. 30 sec.	—	7	$\frac{7}{5}\frac{7}{0}$ths × $\frac{7}{5}\frac{7}{0}$ths	
2 „ .	50	18	$\frac{8}{5}\frac{8}{0}$ths × $\frac{8}{5}\frac{8}{0}$ths	The cardiac impulse is strong.
4 „ .	52	18	$\frac{1}{5}\frac{5}{0}$ths × $\frac{1}{5}\frac{5}{0}$ths	Still on side. The respirations are almost normal in character, and now unaccompanied with moist sounds. Fibrillary muscular twitches very frequent, and occurring over the whole surface. Now and then some spasmodic tremors.
7 „ .	59	—	—	The tremors are less frequent, and the head is occasionally raised.

	Cardiac Contractions, per 10 seconds.	Respirations, per 10 seconds.	Size of Pupils, in fractions of an inch.	General Symptoms, &c.
In 9 min. 30 sec.	61	19	$\frac{1}{5}\frac{7}{0}$ths × $\frac{1}{5}\frac{7}{0}$ths	Saliva has ceased to flow from the mouth.
11 „ 30 „	—	—	—	Has succeeded in turning from side, and is now lying on the abdomen and chest, with the lower jaw resting on the table.
20 „ .	—	20	—	Moist sounds occasionally accompany the respirations. Efforts are made to arch the back. Fibrillary twitches have become so frequent that it is impossible to count the cardiac impulses, but they are ascertained to be very frequent.
25 „ .	—	21	$\frac{1}{5}\frac{7}{0}$ths × $\frac{1}{5}\frac{7}{0}$ths	The back is now arched, but the lower jaw still rests on the table, and the anterior extremities are extended flaccidly at right angles to the body.
30 „ 30 „	61	16	—	The fibrillary twitches are less marked.
36 „ .	—	—	$\frac{1}{5}\frac{7}{0}$ths × $\frac{1}{5}\frac{8}{0}$ths	The rabbit got up and walked a short distance slowly and unsteadily. The transverse diameter of the pupils is greater than the perpendicular.
60 „ .	50	19	$\frac{1}{5}\frac{7}{0}$ths × $\frac{1}{5}\frac{8}{0}$ths	Now and then the rabbit goes about with great difficulty, but usually rests quietly on the abdomen and chest. At rare intervals moist sounds accompany the respirations.
120 „ .	—	—	—	There is only a little difficulty present when the rabbit goes about. It usually sits normally, with slight drooping of the head. The fibrillary twitches are prominently marked.
160 „ .	42	11	$\frac{1}{5}\frac{6}{0}$ths × $\frac{1}{5}\frac{7}{0}$ths	The general condition remains as last noted, except that the fibrillary twitches are now only slightly marked. Neither defæcation nor urination have occurred since the injection of the atropia.

On the following day—twenty-three hours after the commencement of the experiment—the rabbit was lively and well. It was ascertained that the cardiac impulses occurred at the rate of 28, and the respiratory movements at that of 9, in ten seconds. The pupils measured $\frac{1}{5}\frac{5}{0}$ths × $\frac{1}{5}\frac{6}{0}$ths of an inch.

On the fourth day, the restoration of every affected function to a normal state appeared to have been perfected; for now the cardiac contractions and the respiratory movements had returned to their usual rate of 39 and 22 in ten seconds, while the pupils measured $\frac{1}{5}\frac{1}{0}$ths × $\frac{1}{5}\frac{0}{0}$ths of an inch, which exactly corresponded to their measurement before this experiment was made.

Experiment **50-b**.—On the tenth day this rabbit received, by subcutaneous injection, nine-fiftieths of a grain of sulphate of physostigmia. It had previously

been ascertained that the weight of the animal was now three pounds and ten ounces and a half, that the pupils measured $\frac{10}{50}$ths × $\frac{9}{10}$ths of an inch, and that the cardiac contractions were at the rate of 38, and the respirations at that of 15, in ten seconds.

The phenomena usually produced by such a dose quickly made their appearance; among which may be noted a reduction in the rate of the heart's action to 29 in ten seconds, five minutes after the commencement of the administration. Stumbling and excited movements, accompanied with slight increase in the size of the pupils, were, by-and-by, succeeded by partial paralysis, accompanied with frequently recurring tremors, slight contraction of the pupils, noisy infrequent respirations, a flow of saliva from the mouth, and the passage of fæces. In thirteen minutes, the rabbit fell over on the side, the respirations were gasping and obstructed by mucus, the heart's contractions were at the greatly reduced rate of 14 in ten seconds, and the pupils measured only $\frac{7}{50}$ths × $\frac{6}{50}$ths of an inch. Nearly incessantly the limbs were moving in a to-and-fro direction, and occasionally they were affected by more vigorous spasmodic movements. In fifteen minutes and thirty seconds, it was impossible to discover any cardiac impulse, the respirations consisted of rarely occurring gasping movements, the pupils had contracted to $\frac{6}{50}$ths × $\frac{5}{50}$ths of an inch, and the sensibility of the eyeballs had entirely disappeared. Only a few more gasps occurred, and in sixteen minutes after the commencement of the experiment the rabbit was dead.

After death, the first appearance of rigidity was detected in twenty-five minutes, but decided general rigor did not occur until the end of fifty-five minutes (temperature of laboratory 56° F.). At this latter period the pupils measured $\frac{11}{50}$ths × $\frac{10}{50}$ths of an inch.

In the next experiment, also, it is conspicuously shown that atropia is able to prevent the lethal action of physostigma even when its administration is deferred until death appears to be on the point of occurring.

Experiment **51-a**.—In a rabbit, weighing three pounds and eight ounces, it was ascertained that the rate, per ten seconds, of the heart's contractions was 40, and that of the respirations 20, and that the pupils measured $\frac{14}{50}$ths × $\frac{13}{50}$ths of an inch. The rabbit then received, by subcutaneous injection, seventeen-hundredths of a grain of sulphate of physostigmia. The following effects were noted:—

	Cardiac Contractions, per 10 seconds.	Respirations, per 10 seconds.	Size of Pupils, in fractions of an inch.	General Symptoms, &c.
In 1 min. 30 sec.	—	—	—	Slight fibrillary twitches at right side.
3 „ .	—	16	—	Twitches more frequent.
4 „ .	32	—	$\frac{14}{50}$ths × $\frac{13}{50}$ths	A little restlessness.
6 „ .	29	16	—	Movements of lips and mouth.
8 „ .	—	15	$\frac{15}{50}$ths × $\frac{14}{50}$ths	Limbs slightly extended. Shaking a little.

	Cardiac Contractions, per 10 seconds.	Respirations, per 10 seconds.	Size of Pupils, in fractions of an inch.	General Symptoms, &c.
In 10 min. .	—	—	—	Stumbles frequently. Wet fæcal pellets passed.
12 „	—	—	—	Pultaceous fæces passed. The fibrillary twitches are well marked and general. The rabbit is lying on the abdomen and thorax.
14 „ .	—	21	—	The respirations are often accompanied with mucous sounds. Saliva is escaping from the mouth.
17 „ .	—	22	$\frac{1}{5}\frac{2}{0}$ths × $\frac{1}{5}\frac{2}{0}$ths	Tremors occurred, and the rabbit fell on the side, but soon again lay on the abdomen and thorax.
20 „	—	18	$\frac{1}{5}\frac{1}{0}$ths × $\frac{1}{5}\frac{1}{0}$ths	Tremors occurred. Semi-liquid fæces were passed.
23 „ .	22	18	$\frac{1}{5}\frac{0}{0}$ths × $\frac{1}{5}\frac{0}{0}$ths	The respirations are considerably impeded by saliva and mucus. There is no arching of the back, and the lower jaw rests on the table.
26 „ .	19	17	$\frac{9}{5}\frac{}{0}$ths × $\frac{8}{5}\frac{}{0}$ths	The respirations are laboured, and now and again obstructed by mucus, which is removed only after energetic struggles. Rabbit has again fallen over on side, and is unable to turn itself. The fibrillary twitching is now only slight.
28 „ .	11	—	—	Only infrequent laboured respirations occurring at irregular intervals. The rabbit is lying on the side, and movements of the limbs accompany the respirations. The cardiac impulse is very weak.
28 „ 30 sec.	—	—	$\frac{7}{5}\frac{}{0}$ths × $\frac{6}{5}\frac{}{0}$ths	Infrequent and laboured gasps, greatly obstructed by mucus.

At twenty-nine minutes after the commencement of the injection of physostigmia, half a grain of sulphate of atropia was administered to the rabbit by subcutaneous injection, when the symptoms became modified in the following manner :—

	Cardiac Contractions, per 10 seconds.	Respirations, per 10 seconds.	Size of Pupils, in fractions of an inch.	General Symptoms, &c.
In 1 min. .	56	—	$\frac{6}{5}\frac{}{0}$ths × $\frac{5}{5}\frac{}{0}$ths	Rabbit is still on side. Weak struggling gasps occurring.
2 „ .	—	15	—	Respirations are no longer gasping, but they are still accompanied with mucous sounds.
3 „ .	58	—	—	Respirations are less noisy.
6 „ .	—	20	—	Respirations are regular and full, and only occasionally accompanied with moist sounds.
7 „ .	60	—	—	Fibrillary muscular twitches have again become prominent.

	Cardiac Contractions, per 10 seconds.	Respirations, per 10 seconds.	Size of Pupils, in fractions of an inch.	General Symptoms, &c.
In 8 min. .	—	15	$\frac{8}{60}$ths × $\frac{7}{60}$ths	Rabbit is still on the side, but usually quiet, except the shaking that is caused by the incessant fibrillary twitches.
10 „ .	61	—	—	Unsuccessful attempts are made to turn from the side.
11 „ .	—	16	$\frac{1}{6}\frac{6}{0}$ths × $\frac{1}{6}\frac{6}{0}$ths	The respirations are now quite free from mucous sounds. The incessant fibrillary contractions of the muscles cause twitches not only of the skin, but also of the toes, legs, ears, tail, and even eyeballs.
18 „ .	62	18	$\frac{1}{6}\frac{6}{0}$ths × $\frac{1}{6}\frac{6}{0}$ths	After many efforts, the rabbit succeeded in turning from the side.
21 „ .	—	—	—	Some efforts were made to raise the thorax on the anterior extremities, but these efforts excited a series of tremors, during which the rabbit fell on the side.
25 „ .	63	16	$\frac{1}{6}\frac{6}{0}$ths × $\frac{1}{6}\frac{6}{0}$ths	The rabbit has now turned from the side.
28 „ .	—	—	—	A normal sitting posture was assumed and maintained. There is, however, a little drooping of the head.
40 „ .	62	—	—	The rabbit walked about with only a little difficulty.
70 „ .	—	14	$\frac{1}{6}\frac{6}{0}$ths × $\frac{1}{6}\frac{6}{0}$ths	Occasionally some moist sounds are heard accompanying the respirations. There is still a decided degree of weakness present in the anterior extremities. The fibrillary twitches are still incessant in their occurrence.
100 „ .	40	14		The fibrillary twitches have diminished in frequency, but not in the generality of their occurrence, the eyeballs, ears, feet, &c., being still sometimes twitched.
126 „ .	—	—	$\frac{1}{6}\frac{6}{0}$ths × $\frac{1}{6}\frac{6}{0}$ths	The rabbit goes about without any unsteadiness. For the first time since the injection of atropia, some fæcal pellets were now passed, which are rather larger and slightly softer than normal pellets.
190 „ .	35	16	$\frac{1}{6}\frac{6}{0}$ths × $\frac{1}{6}\frac{6}{0}$ths	The general condition of the rabbit seems to be a perfectly normal one. It is only with difficulty that some rarely occurring fibrillary twitches can be detected. A few more fæcal pellets have been passed, but no urine has been voided since the commencement of the experiment.

On the following day this rabbit seemed to be in an absolutely normal condition. It fed largely, and went about actively and well. The pupils measured $\frac{1}{6}\frac{6}{0}$ths × $\frac{1}{6}\frac{6}{0}$ths of an inch, and the rate per ten seconds of the cardiac contractions

was 36, and that of the respiratory movements 18. No further observation was made until the seventh day, when it was found that the heart was contracting 41 times in ten seconds, that the respirations were occurring 20 times in ten seconds, and that the pupils measured $\frac{12}{50}$ths × $\frac{11}{50}$ths of an inch.

The usual testing experiment to prove that the animal had received a lethal dose of physostigma, was made on the ninth day; but in this instance a smaller dose was administered than that from which the animal had already recovered.

Experiment **51-b.**—Having ascertained that the rabbit which formed the subject of the preceding experiment now weighed three pounds five ounces and three quarters, I administered to it, by subcutaneous injection, thirteen one-hundredths of a grain of sulphate of physostigmia. In four minutes thereafter, the rate of the cardiac contractions had diminished to 34 per ten seconds, and in six minutes to 29 per ten seconds. At the latter time, the limbs of the animal were extended, and it stood or went about unsteadily with the body abnormally elevated. Soon afterwards, it became excited, and went about with hurried stumbling movements; and during these movements, it was found that the heart's action was accelerated to the rate of 44 in ten seconds. In fourteen minutes, pultaceous fæces were passed, moisture appeared at the mouth, frequent fibrillary twitches were occurring, and occasionally moist sounds accompanied the somewhat frequent respiratory movements. In seventeen minutes, the pupils were markedly contracted, and the rabbit lay on the abdomen and thorax. In twenty minutes, tremors frequently occurred, the respirations were now laboured and greatly obstructed by mucus and saliva, and the heart contracted only 16 times in ten seconds. The rabbit was dead in twenty-four minutes.

Immediately before death occurred, the pupils became dilated to $\frac{10}{50}$ths × $\frac{10}{50}$ths of an inch; and at the moment of death they became contracted to $\frac{6}{50}$ × $\frac{5}{50}$ths of an inch. After this, their size diminished to $\frac{4}{50}$ths × $\frac{4}{50}$ths of an inch, at one minute and thirty seconds; but soon afterwards, gradual dilatation set in, until they measured $\frac{6}{50}$ths × $\frac{5}{50}$ths of an inch, twenty-four minutes after death. At this time, *post mortem* rigor had appeared in the posterior extremities (temperature of laboratory, 58° F.)

In these various experiments, the influence exerted by atropia upon the action of physostigma is shown to be a most remarkable and conspicuous one, for it effectually counteracts the lethal activity of certain doses of physostigma, whether it be given within a certain time before, simultaneously with, or within a certain time after that substance.

Experiments on Dogs.—The experiments I have described, whereby the existence of this counteraction is demonstrated, were performed on rabbits. In the absence of proof to the contrary, and in the absence likewise of any reasonable grounds for entertaining a different opinion, I feel entitled to assume that this counteraction exists in all the species included in the higher subdivisions

of the animal kingdom. It was, therefore, with the greatest confidence as to the result that the following experiments on dogs were performed.

EXPERIMENT **52-a.**—I injected three-twentieths of a grain of sulphate of atropia, dissolved in 10 minims of distilled water, under the skin at the left flank of a cross-bred Spanish terrier, weighing eleven pounds; and the usual plan was followed of injecting immediately afterwards the washings of the syringe, so as to ensure that the whole of the dose mentioned should be introduced.

At five minutes after the commencement of this injection, a dose of nine-tenths of a grain of sulphate of physostigmia, dissolved in 30 minims of distilled water, was injected under the skin at the right flank, the syringe was washed out with a few drops of water, and this water was injected under the skin at the right hip.

In five minutes after the injection of physostigmia, the dog was lying quietly, apparently but little inconvenienced, and the pupils were dilated. Soon after, distinct fibrillary twitches were observed, a little discomfort was manifested, and quite suddenly the dog fell over on the side. A normal crouching posture was, however, soon assumed, but it was maintained for only a few minutes, and in eleven minutes the dog again fell on the side. A few feeble and unsuccessful efforts were made to turn, soon afterwards incessant tremors made their appearance, and the fibrillary twitches became greatly increased in their frequency and prominence. It was not until fifty minutes after the administration of physostigmia, that any decided evidence of an improvement in the general condition of the dog was observed. It now, however, appeared to take some interest in the events that were occurring near it, and when spoken to, elevated the ears and even slightly raised the head. In fifty-nine minutes, it got up and walked about the room slowly and unsteadily.

On the morning of the second day, the dog eat a large meal with evident satisfaction, and with the exception of some languor and of a slowness in the cardiac contractions, it appeared to be in a normal state. The pupils were now somewhat contracted.

EXPERIMENT **52-b.**—On the eleventh day—ten days after the performance of the previous experiment,—the dog, being active and well, and weighing eleven pounds and four ounces, received, by subcutaneous injection, three-tenths of a grain of sulphate of physostigmia dissolved in 20 minims of distilled water. Immediately before this injection, it was ascertained that the heart's contractions occurred at the rate of 23 in ten seconds.

The first obvious effect occurred in five minutes, and consisted in the production of fibrillary twitches. In seven minutes, fæces were passed; and soon afterwards, there was some unsteadiness in the movements, and gentle tremors and almost incessant movements of the lips and mouth took place.

In nine minutes, the dog lay down, but almost at once rose again, though with great difficulty; and now frothy saliva escaped from the mouth. In ten minutes, it was lying extended on the floor, with the head resting on the lower jaw. In eleven minutes, the head fell on the side, starts frequently occurred, the respirations were gasping, laboured, and obstructed by mucus, and well-marked fibrillary twitchings were present, which involved the whole surface of the animal, and seemingly the deeper muscles also. In thirteen minutes, the animal was altogether on the side, in a flaccid state. In fifteen minutes, the heart's contractions occurred at the rate of only 4 in ten seconds, and so long were the intervals between the feeble respiratory gasps that more than once it was thought to be dead. This event, however, did not occur until two minutes afterwards, or seventeen minutes after the commencement of the administration of physostigmia.

In the two next experiments, atropia and physostigma were injected nearly simultaneously.

Experiment **53-a.**—A vigorous English terrier dog, weighing ten pounds, received, by subcutaneous injection, eight grains of sulphate of atropia, dissolved in 80 minims of distilled water, and immediately afterwards, three grains of extract of physostigma, suspended in forty minims of distilled water. These injections, as well as those subsequently made, by which the washings of the syringes were introduced under the skin, occupied altogether two minutes.

The chief symptoms that appeared were dilatation of the pupils, partial paralysis, frequent vomiting, and hypnotism. Of these, the first continued for several days, and the two last for less than twenty-four hours. The partial paralysis was nearly completely recovered from in forty minutes, after which, the dog was in a perfectly normal condition, except that the pupils were in full dilatation and that a tendency to sleep was manifested.

Experiment **53-b.**—Three weeks afterwards, this dog being now ten pounds and two ounces in weight, received, by subcutaneous injection, eight grains of sulphate of atropia, and immediately afterwards six grains of extract of physostigma.

Dilatation of the pupils and considerable loss of motor power were again produced, but no vomiting occurred. In addition to these symptoms, however, certain others appeared that were undoubtedly due to physostigma poisoning, such as tremors and exaggerated bronchial and salivary secretions. The paralysis and tremors continued for more than three hours, and the dilatation of the pupils for several days, after which the dog perfectly regained its former condition.

Experiment **53-c.**—Fifteen days after the second of these experiments, this dog, being in every respect in a normal condition, received, by subcutaneous injection, three grains of extract of physostigma—a dose equal to that from which

it recovered in the first experiment, and only one-half as large as that from which it recovered in the second. The results were, that fibrillary twitches, partial paralysis, and tremors were quickly produced; that the lachrymal, salivary, and bronchial secretions were profusely increased; that the cardiac contractions became gradually slower and slower; that defæcation and urination occurred; and that the respirations became more and more laboured and shallow, until they ceased on the occurrence of death, at seventeen minutes after the administration.

It was ascertained after death, that the weight of the dog was ten pounds and one ounce.

In the experiment that will now be described, atropia was administered five minutes after a lethal dose of sulphate of physostigmia had been injected under the skin.

Experiment **54-a.**—An active young Scotch terrier dog, weighing ten pounds and three ounces, received, by subcutaneous injection, three-fifths of a grain of sulphate of physostigmia, dissolved in 25 minims of distilled water.

Before the injection, the rate per ten seconds of the cardiac impulses was 32, and that of the respirations 4, and the size of the pupils, in a full light, was $\frac{12}{50}$ths × $\frac{12}{50}$ths of an inch.

In two minutes after the commencement of the administration, symptoms of discomfort were manifested, and the lips were moved and licked with the tongue, as if an unusual quantity of fluid were present in the anterior part of the mouth. In four minutes, slight tremors frequently occurred, and fibrillary twitches were present.

In five minutes, a solution containing three-tenths of a grain of sulphate of atropia in 15 minims of distilled water, was injected under the skin at the right flank. In two minutes thereafter, the tremors already noted had become more prominent and strong, the limbs were unable properly to support the body, urine was voided, saliva escaped from the mouth, and the eyeballs were unnaturally moist. The tremors and weakness quickly increased, so that, on account of the former, it became impossible to determine the rate of the cardiac and respiratory movements; while, on account of the latter, stumbles occurred, and the head began to droop, until often it touched the floor. In five minutes, the pupils were greatly dilated, but now the secretions of the salivary and lachrymal glands were diminished. In seven minutes, the dog lay quietly on the abdomen and thorax, and in thirteen minutes, it fell over on the side. An endeavour was made to count the cardiac impulses; but when the hand was placed over the heart, the tremors referred to became so greatly increased that it was impossible to distinguish the heart's impulse. It was not until thirty-eight minutes that an attempt to count the heart's contractions was successful, and then it was found that the impulse occurred at the rate of 45 in ten seconds. At the same time, the respirations had a rate of 7 in ten seconds, and

the pupils measured $\frac{17}{50}$ths × $\frac{17}{50}$ths of an inch. In forty-eight minutes, the condition of the dog had so far improved, that, after some efforts, it rose on the limbs, and then lay down in a normal crouching attitude, with the head raised. In fifty-three minutes, the dog attempted to vomit, but it was not until one hour and sixteen minutes that emesis occurred. Soon afterwards, it again got up and walked about the room, with only a little unsteadiness. In one hour and fifty-five minutes, the animal seemed to be perfectly well. The rate per ten seconds of the cardiac contractions was 47, and that of the respirations 10, and the pupils measured about $\frac{17}{50}$ths × $\frac{17}{50}$ths of an inch. During all this time, urine had been voided only once, and no fæces had been passed.

On the following day, the dog was active and in a perfectly normal general condition. The cardiac impulses occurred at the rate of 48, and the respiratory movements at that of 5, in ten seconds, while the pupils measured $\frac{16}{50}$ths × $\frac{16}{50}$ths of an inch.

It was not, however, until the sixth day that the heart's action had become reduced to the normal frequency of about 30 contractions in the ten seconds and the pupils remained more or less dilated for other eight days, but on the fifteenth day they had returned to the condition that existed previously to the experiment.

This dog afterwards received without any atropia a dose of physostigmia only one-half as large as that from which it recovered when atropia also was given, and the following effects were produced:—

Experiment **54-b.**—Nineteen days after the performance of the previous experiment, the dog that had been used in it received, by subcutaneous injection, three-tenths of a grain of sulphate of physostigmia, dissolved in a small quantity of distilled water. In five minutes, symptoms of discomfort, slight unsteadiness of the limbs, and fibrillary twitches were observed; and soon after, struggling and stumbling movements occurred, and the flow of tears and saliva became increased. In eight minutes, decided paralysis of the posterior extremities was present. In ten minutes, the dog lay down on the abdomen, and rested the lower jaw on the floor. Series of gentle tremors succeeded each other in rapid succession, and at the end of one of them the dog fell over on the side. Saliva now escaped freely from the mouth, wet and soft fæces were passed, and the respirations became rapid, noisy, and shallow. In fifteen minutes, the respirations were very laboured and jerking, though still abnormally frequent, and the tremors had somwhat increased in severity. In a short time, however, the tremors became less severe and frequent, but at the same time the respiratory movements became laboured, somewhat shallow, and greatly obstructed by mucus accumulated in the mouth and larynx, and the cardiac impulse became infrequent and weak. In ninteen minutes, the respirations consisted merely of rarely occurring gasps, the pupils were contracted, and the sensibility of the

eyeballs had disappeared, while it was only with difficulty that now and again a cardiac impulse could be detected. The gasping respiratory efforts became gradually separated from each other by longer and longer intervals, until they altogether ceased at twenty-two minutes after the commencement of the injection of physostigmia.

After death, it was ascertained that the weight of the dog was ten pounds and four ounces.

It is shown by these experiments, that in dogs, as in rabbits, atropia exerts a powerful counteracting influence to the lethal action of physostigma. It would have been a matter of surprise had this result not been obtained, for there was no reason to anticipate that either atropia or phyostigma would act otherwise than in comformity with the general law, that every active substance influences the same histological structures in the same way in whatever animal these structures are present. No doubt the prominence and importance of the results that are produced by essentially the same action vary somewhat in different animals; but in judging of the probable existence of an antagonism between two substances, the prominence or importance of an effect resulting from any primary action is of secondary moment to the fact of the existence of the action. Accordingly, if atropia be capable of producing upon one species of animal an influence of such a nature as to antagonise in it the lethal action of physostigma, it is difficult to imagine why it should not produce the same antagonising influence in all animals of equally high development. The mere fact of there being a difference in the lethal activity of atropia in different animals, is not sufficient to lead to the supposition that it will not in them successfully counteract the lethal action of physostigma; for the same primary actions are produced, notwithstanding the differences that may exist in the lethal activity. Many circumstances of a more or less accidental nature may modify the lethal activity of poisonous substances, and among these is the manner in which the substance is administered. In the case of atropia, its lethal activity in rabbits may be enormously increased by introducing it directly into a blood-vessal.

Experiments in which Atropia was injected into a vein and Physostigma under the skin.—It seemed therefore of importance to administer atropia by injection into a vein, in order to determine whether, when so administered, it still, notwithstanding the great increase that is thus produced in its lethal activity, retains the power to counteract the lethal action of physostigma.

Experiment **55-a**.—A rabbit, weighing four pounds, was secured by means of a Czermak's rabbit-holder, and one of the external facial veins was exposed, and two ligatures were loosely applied to a small portion of it dissected from its connections. Two grains of extract of physostigma was then administered to the rabbit by subcutaneous injection.

Five minutes afterwards, a thirtieth of a grain of sulphate of atropia, dissolved in 10 minims of distilled water, was injected into the exposed facial vein. The previously applied ligatures were then carefully secured, and the incision closed by silk sutures. On the animal being set free, it was observed that movements were performed with difficulty. In seven minutes after the injection of atropia, the animal lay down on the abdomen and thorax, occasionally mucous sounds were heard with the respirations, and it was observed that the entire surface of the animal was affected with fibrillary twitches. In eight minutes, the pupils were dilated ($\frac{1}{50}$ths $\times$ $\frac{1}{50}$ths of an inch), the animal had assumed a normal sitting posture, and mucous sounds no longer accompanied the respirations. Indeed, with the exception of great dilatation of the pupils and fibrillary twitches, the rabbit seemed perfectly well. In seventeen minutes, however, symptoms of paralysis again appeared, and wet fæces were passed; while in twenty-three minutes, the respirations again became accompanied with mucous sounds, and the dilatation of the pupils somewhat diminished. These symptoms continued, without any improvement in the condition of the animal, for twenty-six minutes; but in forty-six minutes after the injection of atropia, the rabbit raised itself with some difficulty, and went about unsteadily. The pupils now measured $\frac{1}{50}$ths $\times$ $\frac{1}{50}$ths of an inch, the respirations were laboured and noisy, and often the rabbit went about in a very excited manner. In one hour and fifteen minutes, a large quantity of urine was voided, and pultaceous fæces were passed. It was not until three hours and ten minutes after the injection of atropia that a nearly normal condition was assumed, and at this time no symptoms were present except dilatation of the pupils, and rarely occurring mucous respiratory sounds. Ultimately the rabbit recovered perfectly, and it was afterwards subjected to the action of a lethal though smaller dose of physostigma than that from which it had thus recovered.

Experiment **55-b.**—Seven days after the performance of the last experiment, the rabbit which had been used in it received, by subcutaneous injection, one grain and seven-tenths of extract of physostigma.

Previously to the performance of the injection, it was ascertained that the weight of the rabbit was four pounds and three ounces; that the rate, per ten seconds, of the cardiac contractions was 47, and that of the respirations 29; and that the pupils measured $\frac{1}{50}$ths $\times$ $\frac{1}{50}$ths of an inch.

After the injection, symptoms of poisoning quickly manifested themselves, and in seven minutes the rabbit was suffering from well-marked general paralysis, the rate per ten seconds of the cardiac contractions was 39, and that of the respirations 28; while the pupils measured $\frac{1}{50}$ths $\times$ $\frac{1}{50}$ths of an inch. A short period occurred during which the limbs were extended, and stumbling, excited movements took place, and then the rabbit fell on the abdomen and thorax, the respirations became noisy, wet and soft fæces were passed, and tremors

succeeded each other at short intervals. In twelve minutes, the respirations were laboured, and at the rate of 15 in ten seconds, the cardiac contractions occurred 34 times in ten seconds, and the pupils measured only $\frac{10}{50}$ths × $\frac{9}{50}$ths of an inch. The respiratory embarrassment soon became much greater, and at the same time the general paralysis increased; until, in twenty-one minutes, only laboured, gasping and noisy respirations took place, the rabbit fell over on the side, the pupils contracted to $\frac{4}{50}$ths × $\frac{3}{50}$ths of an inch, and the cardiac contractions were weak, and occurred only 12 times in ten seconds. At twenty-three minutes after the administration of physostigma, the rabbit was dead.

This method of administration was followed in the next experiment likewise.

Experiment **56-a.**—Having exposed one of the external facial veins on the left side of a rabbit, weighing three pounds and two ounces, I injected under the skin, at the left flank, one grain and three-fifths of extract of physostigma, mixed with 15 minims of distilled water.

Five minutes afterwards, I injected into the exposed and dissected vein a forty-fifth of a grain of sulphate of atropia, dissolved in 8 minims of distilled water. The vein was then ligatured, the wound closed with silk sutures, and the rabbit set free from the Czermak's holder by which it had been secured.

In nine minutes after the injection of sulphate of atropia, the rabbit was lying on the abdomen and chest, frequent fibrillary twitches were occurring over the whole surface, the pupils were dilated, and the cardiac action was abnormally frequent. In twenty-three minutes, it rose and went about, though somewhat unsteadily. From this time, the general condition of the rabbit steadily improved, until, in one hour and thirty minutes, there were no symptoms present except pupillary dilatation, abnormal frequency of cardiac action, and slight fibrillary twitches. During the experiment, there had not been any obvious increase in the secretions of the salivary, bronchial, or lachrymal glands; nor did defæcation or urination take place until more than two hours and fifteen minutes after the experiment had been commenced.

Experiment **56-b.**—The rabbit that had formed the subject of the preceding experiment received, eight days afterwards, one grain and three-tenths of extract of physostigma, suspended in a few minims of distilled water. At this time the weight of the rabbit was three pounds and four ounces.

In nine minutes after the injection of the extract, the rabbit was lying on the abdomen and chest, affected with pretty severe tremors, and breathing somewhat rapidly and noisily. In fourteen minutes, the pupils were contracted, and the respirations were laboured and embarrassed by an accumulation in the mouth of mucus and saliva, while the cardiac contractions were occurring infrequently. By this time, also, a considerable quantity of soft and pultaceous

fæces had been passed. In fifteen minutes, the rabbit was lying on the side, and laboured and infrequent gasping respirations were occurring. Soon afterwards, the sensibility of the conjunctiva disappeared, the cardiac impulses became extremely weak, and it was only at long intervals that a feeble gasp occurred. Death occurred at nineteen minutes after the administration of physostigma.

It is shown by these two experiments that in rabbits atropia retains its remarkable power of counteracting the lethal action of physostigma even when its toxic activity in these animals is greatly increased.

Experiment with a Preparation of Physostigma different from that used in all the other Experiments.—As the preceding experiments were, without exception, made with extract of physostigma and sulphate of physostigmia prepared by myself, it seemed not altogether superfluous to check the results that were obtained, by making some additional experiments with a preparation for whose activity and properties I was not responsible. Accordingly, several experiments were made with an extract prepared by Dr Cook, of the well-known firm of Messrs T. and H. Smith. With this extract essentially the same results were obtained as with the preparations used in all the other experiments. It is, therefore, unnecessary to give a description of more than one experiment in which it was employed.

Experiment **57-a.**—A rabbit, weighing three pounds and eight ounces, received, by subcutaneous injection, two grains of Dr Cook's extract of physostigma, suspended in 40 minims of distilled water. One minute and a half afterwards, it received, also by subcutaneous injection, half a grain of sulphate of atropia, dissolved in 10 minims of distilled water.

In three minutes after the injection of sulphate of atropia, the pupils measured $\frac{14}{50}$ths × $\frac{14}{50}$ths of an inch, the measurement immediately before the experiment having been $\frac{10}{50}$ths × $\frac{9}{50}$ths. In seven minutes, the pupils measured $\frac{16}{50}$ths × $\frac{16}{50}$ths of an inch, the rate of the heart's contractions was considerably accelerated, fibrillary twitches were occurring, and a little restlessness was present. In thirteen minutes, this restlessness had become somewhat greater, and the animal had decided difficulty in moving about. Soon afterwards the pupils became still more dilated, and in eighteen minutes they measured $\frac{18}{50}$ths × $\frac{17}{50}$ths of an inch. In twenty-five minutes, the difficulty in moving about had become greater—even to such an extent that often the anterior extremities yielded, and the rabbit fell on the thorax. It appeared also to be in a somewhat excited state, as confused and stumbling movements were frequently made. In fifty-two minutes, the pupils measured $\frac{15}{50}$ths × $\frac{14}{50}$ths of an inch, but no obvious change had occurred in the general condition of the animal. In one hour and ten minutes, however, evidences of recovery were manifested; the rabbit went about with but little difficulty, no restless excitement was present, and frequently a perfectly normal sitting posture was assumed. Indeed, the only symptom of an

abnormal condition that was distinctly apparent consisted of frequently occurring and well-marked fibrillary twitches. From this time the condition of the animal steadily improved until perfect recovery took place.

EXPERIMENT **57-b.**—Nine days afterwards, the rabbit which formed the subject of the previous part of this experiment received, by subcutaneous injection, one grain of Dr COOK's extract of physostigma, suspended in 20 minims of distilled water. Before the injection was made, it was ascertained that the weight of the rabbit was three pounds and eight ounces and a half, and that the pupils measured $\frac{11}{50}$ths × $\frac{10}{50}$ths of an inch.

Symptoms of poisoning very quickly appeared. In six minutes, the posterior extremities were trailing, and the anterior considerably extended, and stumbling movements occurred, while well-marked fibrillary twitches were present. In eight minutes, saliva was escaping from the mouth in drops, and tremors frequently occurred. In eleven minutes, the rabbit was lying on the abdomen and chest; several fæcal pellets were passed; the pupils were contracted ($\frac{7}{50}$ths × $\frac{5}{50}$ths of an inch); and the respirations were rapid and accompanied with mucous sounds. Soon afterwards, the head subsided until the lower jaw rested on the table; the arching of the back disappeared; the pupils became still further contracted ($\frac{4}{50}$ths × $\frac{3}{50}$ths of an inch); the cardiac contractions greatly diminished in frequency and strength; and the respiratory movements assumed a gasping character. Feeble tremors then occurred, and the head was drawn backwards; after which a condition of general flaccidity set in. A few more feeble gasps occurred, and then the respirations altogether ceased, at thirteen minutes and thirty seconds after the commencement of the injection of physostigma.

In this experiment the power of atropia to counteract the lethal action of the extract of physostigma prepared by Dr COOK is displayed in a very remarkable manner.

The second portion of the experiment shows that the lethal activity of this extract is considerably greater than that of the extract prepared by myself. Nevertheless, atropia so completely and successfully antagonised the lethal action, as to prevent the occurrence of any symptom of serious import after the administration of a dose twice as large as that by which death was afterwards produced in about thirteen minutes.

Summary of the preceding Experiments.—Before passing to the second portion of this research, it may be of advantage to give a brief summary of the various facts that have been brought forward.

1. It has been shown by a statement of the result of several experiments, that the minimum lethal dose for rabbits of extract of physostigma is 1·2 grain, and that of sulphate of physostigmia 0·12 grain, for every three pounds weight of animal.

2. The influence that is exerted by atropia upon the lethal action of extract of physostigma and sulphate of physostigmia has been examined in rabbits, and a description has been given of several experiments that were performed for this purpose. The following facts have been stated among the conditions and results of these experiments :—

EXPERIMENT **41-a.**—A rabbit, weighing 2 lbs. 15½ oz., received 0·3 grain of sulphate of atropia; and, five minutes afterwards, 1·2 grain of extract of physostigma. Recovery took place.

41-b.—Ten days afterwards, the same rabbit, now weighing 3 lbs., received 1·2 grain of extract of physostigma. Death occurred in twenty-two minutes.

EXPERIMENT **42-a.**—A rabbit, weighing 3 lbs. 4 oz., received 0·17 grain of sulphate of atropia; and, five minutes afterwards, 3·9 grains of extract of physostigma. Recovery took place.

42-b.—Eight days afterwards, the same rabbit, now weighing 3 lbs. 5 oz., received 1·3 grain of extract of physostigma. Death occurred in thirty-one minutes.

EXPERIMENT **43-a.**—A rabbit, weighing 3 lbs., received 0·5 grain of sulphate of atropia; and, five minutes afterwards, 0·24 grain of sulphate of physostigmia. Recovery took place.

43-b.—Nine days afterwards, the same rabbit, now weighing 3 lbs. ½ oz., received 0·24 grain of sulphate of physostigmia. Death occurred in nine minutes and fifty seconds.

EXPERIMENT **44-b.**—A rabbit, weighing 3 lbs. 12 oz., received 0·5 grain of sulphate of atropia; and, nearly at the same time, 3 grains of extract of physostigma. Recovery took place.

44-b.—Nine days afterwards, the same rabbit, now weighing 3 lbs. 12½ oz., received 1·5 grain of extract of physostigma. Death occurred in fifty-four minutes.

EXPERIMENT **45-a.**—A rabbit, weighing 2 lbs. 8 oz., received 0·5 grain of sulphate of atropia; and, nearly at the same time, 1 grain of extract of physostigma. Recovery took place.

45-b.—Thirteen days afterwards, the same rabbit, now weighing 2 lbs. 9 oz., received 1 grain of extract of physostigma. Death occurred in eighteen minutes.

EXPERIMENT **46-a.**—A rabbit, weighing 3 lbs. 2 oz., received 2·5 grains of extract of physostigma; and, five minutes afterwards, 0·5 grain of sulphate of atropia. Recovery took place.

46-b.—Eleven days afterwards, the same rabbit, now weighing 3 lbs. 2¾ oz., received 2·5 grains of extract of physostigma. Death occurred in eleven minutes and thirty seconds.

EXPERIMENT **47-a.**—A rabbit, weighing 3 lbs. 11½ oz., received 2 grains of extract of physostigma; and, eight minutes and thirty seconds afterwards, 0·5 grain of sulphate of atropia. Recovery took place.

47-b.—Four days afterwards, the same rabbit, now weighing 3 lbs. 8 oz., received 1·5 grain of extract of physostigma. Death occurred in fifteen minutes and thirty seconds.

EXPERIMENT **48-a.**—A rabbit, weighing 2 lbs. 14 oz., received 1·5 grain of extract of physostigma; and, ten minutes and thirty seconds afterwards, 0·5 grain of sulphate of atropia. Recovery took place.

48-b.—Twelve days afterwards, the same rabbit, now weighing 3 lbs. 1 oz., received 1·2 grain of extract of physostigma. Death occurred in thirty minutes.

EXPERIMENT **49-a.**—A rabbit, weighing 3 lbs. 3 oz., received 1·5 grain of extract of physostigma; and, ten minutes and thirty seconds afterwards, 0·5 grain of sulphate of atropia. Recovery took place.

49-b.—Nine days afterwards, the same rabbit, now weighing 3 lbs. 5 oz., received 1·3 grain of extract of physostigma. Death occurred in forty-six minutes and ten seconds.

EXPERIMENT **50-a.**—A rabbit, weighing 3 lbs. 10 oz., received 0·18 grain of sulphate of physostigmia; and, fifteen minutes and ten seconds afterwards, 0·7 grain of sulphate of atropia. Recovery took place.

50-b.—Nine days afterwards, the same rabbit, now weighing 3 lbs. 10½ oz., received 0·18 grain of sulphate of physostigmia. Death occurred in sixteen minutes.

EXPERIMENT **51-a.**—A rabbit, weighing 3 lbs. 8 oz., received 0·17 grain of sulphate of physostigmia; and, twenty-nine minutes afterwards, 0·5 grain of sulphate of atropia. Recovery took place.

51-b.—Eight days afterwards, the same rabbit, now weighing 3 lbs. 5¾ oz., received 0·13 grain of sulphate of physostigmia. Death occurred in twenty-four minutes.

3. Several experiments have been described, in which the influence exerted by atropia upon the lethal action of extract of physostigma and sulphate of physostigmia was examined in dogs also. The following facts were stated among the conditions and results of these experiments :—

EXPERIMENT **52-a.**—A dog, weighing 11 lbs., received 0·15 grain of sulphate of atropia, and, five minutes afterwards, 0·9 grain of sulphate of physostigmia. Recovery took place.

52-b.—Ten days afterwards, the same dog, now weighing 11 lbs. 4 oz., received 0·3 grain of sulphate of physostigmia. Death occurred in seventeen minutes.

EXPERIMENT **53-a.**—A dog, weighing 10 lbs., received 8 grains of sulphate of atropia, and, immediately afterwards, 3 grains of extract of physostigma. Recovery took place.

53-b.—Three weeks afterwards, the same dog, now weighing 10 lbs. 2 oz., received 8 grains of sulphate of atropia, and, immediately afterwards, 6 grains of extract of physostigma. Recovery took place.

53-c.—Fifteen days after the second experiment, the same dog, now weighing 10 lbs. 1 oz., received 3 grains of extract of physostigma. Death occurred in seventeen minutes.

EXPERIMENT **54-a.**—A dog, weighing 10 lbs. 3 oz., received 0·6 grain of sulphate of physostigmia, and, five minutes afterwards, 0·3 grain of sulphate of atropia. Recovery took place.

54-b.—Nineteen days afterwards, the same dog, now weighing 10 lbs. 4 oz., received 0·3 grain of sulphate of physostigmia. Death occurred in twenty minutes.

Although these experiments clearly demonstrate that atropia is able to counteract the lethal action of physostigma in rabbits and dogs, it is possible to suppose that it will not do so in other animals of equally high development. Some support is given to this surmise by evidence tending to show that the action of atropia in certain animals is different from its action in others. The only difference, however, that is known to exist, is in the lethal activity of the substance, relatively to certain animals; and in rabbits and dogs, this lethal activity is less than in several other animals. Accordingly, if the lethal activity of atropia for rabbits and dogs be increased, and if, notwithstanding this increase, successful antagonism be still produced in them, the only reason for supposing that successful antagonism will not be produced in certain other animals will be shown to be an insufficient one. For any given species of animal, the lethal activity of atropia may be modified by the method of administration, and it is very much greater when this substance is directly introduced into the blood-stream, than when it is injected under the skin.

4. The influence exerted on the lethal action of physostigma by atropia injected directly into the blood-stream, was examined by experiments on rabbits.

The following facts were stated among the conditions and results of these experiments :—

EXPERIMENT **55-a.**—A rabbit, weighing 4 lbs., received 2 grains of extract of physostigma; and, five minutes afterwards, 0·03 grain of sulphate of atropia by injection into a facial vein. Recovery took place.

55-b.—Seven days afterwards, the same rabbit, now weighing 4 lbs. 3 oz., received 1·7 grain of extract of physostigma. Death occurred in twenty-three minutes.

EXPERIMENT **56-a.**—A rabbit, weighing 3 lbs. 2 oz., received 1·6 grain of extract of physostigma, and, five minutes afterwards, 0·02 grain of sulphate of atropia by injection into a facial vein. Recovery took place.

56-b.—Eight days afterwards, the same rabbit, now weighing 3 lbs. 4 oz., received 1·3 grain of extract of physostigma. Death occurred in nineteen minutes.

5. An experiment was described, which had been undertaken to determine whether a preparation of physostigma, different from that used in any of the other experiments of this research, has its lethal action counteracted by sulphate of atropia. The following facts were stated among the conditions and results of this experiment:—

EXPERIMENT **57-a.**—A rabbit, weighing 3 lbs. 8 oz., received 2 grains of extract of physostigma, prepared by Dr COOK; and, one minute and thirty seconds afterwards, 0·5 grain of sulphate of atropia. Recovery took place.

57-b.—Nine days afterwards, the same rabbit, now weighing 3 lbs. 8½ oz., received 1 grain of extract of physostigma, prepared by Dr COOK. Death occurred in thirteen minutes and thirty seconds.

These various experiments prove so clearly that atropia is able to counteract the lethal action of physostigma, as to be of themselves sufficient for the purposes of this section. Their evidence may, however, be largely added to from the very numerous experiments that were necessarily performed in the second portion of this research.

Section B.—DETERMINATION OF THE EXTENT OF THE COUNTERACTING INFLUENCE OF ATROPIA UPON THE LETHAL ACTION OF PHYSOSTIGMA.

In the "preliminary note" which I communicated to this Society, on the antagonism between physostigma and atropia, the opinion was expressed, that as this antagonism is "concerned with two substances, each of which possesses a number of actions, it is not unreasonable to anticipate that several of them are not mutually antagonistic," and that "above certain doses, a region may, therefore, be entered where the non-antagonised actions are present in sufficient degrees to be themselves able to produce fatal results."* Besides this consideration, there are others derived from our knowledge of the physiological action of physostigma, which render it probable that such a region exists.

Certain of the actions of the two substances are of a similar nature. When a dose not much above the minimum-lethal of the one is counteracted by a small dose of the other, the similar actions are not produced in sufficient intensity to become, even in combination, important toxic actions. When, however, a dose considerably above the minimum lethal of the one substance is given along with a large dose of the other, the similar actions may be produced in such intensity as to assume the importance of lethal actions.

Further, with regard to the counteracting actions themselves, it is to be observed that various of the facts mentioned in the record of experiments that is given in the preceding section tend to make mutual antagonism probable, not only of one but of several of the actions of physostigma and atropia; and it is legitimate to suppose, that with a given dose of physostigma, the counteraction produced by a certain amount of atropia will be more perfect in the case of one or more of the antagonistic actions than in that of others, and that with certain doses of the two substances such incompleteness of counteraction may exist as would, even without the occurrence of *non*-antagonised action, suffice for the production of death.

Guided by these considerations, I anticipated that the counteracting influence of atropia upon the lethal action of physostigma is successfully exerted only within a definite range of doses, and that this range may be determined by experimental research. The somewhat laborious task of making this determination has been undertaken because it seemed likely that results would thereby be obtained of the greatest interest and novelty, in connection not only with this special instance of counteraction, but also with the general subject of physiological antagonism and its important and direct bearing on the principles of therapeutics.

* *Loc. cit.*, p. 589.

In order to define the limits of the counteracting influence of atropia upon the lethal action of physostigma, three series of experiments were made.

The chief objects of the two first of these were to ascertain the maximum dose of physostigma that can be successfully antagonised by atropia, and the range of doses of atropia that can successfully antagonise lethal doses of physostigma. In each series, a constant interval of time was maintained between the administration of the two substances; but in the first, atropia was administered five minutes before physostigma, while in the second, physostigma was administered five minutes before atropia. These intervals of time were selected in preference to simultaneous administration because, practically, it is impossible for one experimenter to inject the two substances into different regions exactly at the same moment, and further, because it seemed probable that a difference would be found to exist in the counteracting power of atropia according as it is given before or after physostigma. In both of these series, experiments were made, in the first place, with the minimum-lethal dose of physostigma, and in combination with it, various doses of atropia were administered, ranging from one that was too small to prevent the lethal action, through a number that were able to prevent death, until a dose was found whose administration resulted in death. Similar experiments were made with a dose of physostigma one and a half times as large as the minimum-lethal, then with one twice as large as the minimum-lethal, and so on, at the same rate of progression, until a dose of physostigma was reached that was too large to be successfully antagonised by any dose of atropia.

The chief object of the third series of experiments was to ascertain within what limits of time between the administration of the two substances successful antagonism occurs. In the experiments of this series, a constant dose of physostigma was given along with various doses of atropia, and with each dose of atropia several experiments were made which differed from each other by a difference in the interval of time between the administration of the two substances. On this plan two sets of experiments were performed, in one of which atropia was given before physostigma, and in the other of which it was given after; and subsequently these two sets of experiments were connected together by a third, in which atropia, in various doses, was administered nearly simultaneously with the same dose of physostigma as was given in the two other sets of experiments.

All the experiments of this portion of the research were performed on rabbits. In the great majority of the experiments, the weight of the animal was about three pounds, but when it was below or in excess of this, the doses of the substances administered were calculated for three pounds weight of animal.

In the description that will now be given of these experiments, the doses

per three pounds weight of rabbit will alone be mentioned. For further details, and more especially for the actual doses, the weight of the animals, and the chief symptoms, I must refer to the Tabular Summary at the end of the paper.

1. Determination of the Limits of Antagonism when Atropia is administered Five Minutes before Physostigma.

In this series of experiments, physostigma was administered in the form of extract. It has already been shown that the minimum lethal dose of this preparation is 1·2 grain per three pounds weight of rabbit.

Experiments with the Minimum-Lethal Dose of Physostigma.—In accordance with the plan which has been indicated, the first experiments of the series were made to determine what doses of atropia can prevent the fatal action of the minimum-lethal dose of physostigma. In the experiments performed for this purpose,* the following results were obtained:—

Experiment **71.**†	With	0·005	grain	of sulphate of atropia,	death occurred.
Experiment **72-a.**	,,	0·009	,,	,,	recovery ,,
Experiment **73-a.**	,,	0·015	,,	,,	recovery ,,
Experiment **74-a.**	,,	0·02	,,	,,	recovery ,,
Experiment **75-a.**	,,	0·025	,,	,,	recovery ,,
Experiment **76-a.**	,,	0·031	,,	,,	recovery ,,
Experiment **77-a.**	,,	0·05	,,	,,	recovery ,,
Experiment **41-a.**‡	,,	0·3	,,	,,	recovery ,,
Experiment **78-a.**	,,	0·92	,,	,,	recovery ,,
Experiment **79-a.**	,,	2·	grains	,,	recovery ,,
Experiment **80-a.**	,,	3·	,,	,,	recovery ,,
Experiment **81-a.**	,,	4·3	,,	,,	recovery ,,
Experiment **82-a.**	,,	5·	,,	,,	recovery ,,
Experiment **83-a.**	,,	5·2	,,	,,	recovery ,,
Experiment **84.**	,,	5·3	,,	,,	death ,,
Experiment **85.**	,,	5·3	,,	,,	death ,,
Experiment **86.**	,,	5·4	,,	,,	death ,,
Experiment **87.**	,,	5·5	,,	,,	death ,,

* Tabular Summary, Series 1, Table 2.

† Except in two cases, the numbers of these experiments have reference to the arrangement that has been followed in the Tabular Summary at the end of the paper, where the leading facts connected with all the experiments belonging to this Section of the research are mentioned.

‡ A full description of the experiment has already been given in Section A. (see p. 544).

It is shown by this brief statement of the experiments with the minimum-lethal dose of physostigma, that while one two-hundredth of a grain of sulphate of atropia is a dose insufficient to prevent death, nine one-thousandths of a grain is one sufficiently large to do so; that any dose of sulphate of atropia ranging within the wide limits extending from the nine one-thousandths of a grain to five grains and one fifth is able to prevent the fatal effect of this dose of physostigma; and that if the dose of sulphate of atropia amount to five grains and three-tenths, the region of successful antagonism is left, and death occurrs.

Experiments with One and a half times the Minimum-Lethal Dose of Physostigma.—In the next place, experiments were made to determine what doses of atropia are able successfully to counteract a dose of physostigma one and a half times as large as the minimum-lethal.* The following results were obtained:—

EXPERIMENT **88.**—With	0·014	grain	of sulphate of atropia,	death	occurred.
EXPERIMENT **89.** „	0·015	„	„	death	„
EXPERIMENT **90-a.** „	0·02	„	„	recovery	„
EXPERIMENT **91.** „	0·02	„	„	death	„
EXPERIMENT **92-a.** „	0·02	„	„	recovery	„
EXPERIMENT **93-a.** „	0·03	„	„	recovery	„
EXPERIMENT **94-a.** „	0·05	„	„	recovery	„
EXPERIMENT **95-a.** „	0·05	„	„	recovery	„
EXPERIMENT **96-a.** „	1·5	„	„	recovery	„
EXPERIMENT **97-a.** „	2·	grains	„	recovery	„
EXPERIMENT **98-a.** „	2·6	„	„	recovery	„
EXPERIMENT **99-a.** „	3·3	„	„	recovery	„
EXPERIMENT **100-a.** „	4·1	„	„	recovery	„
EXPERIMENT **101.** „	4·3	„	„	death	„

From these experiments, it appears that while three two-hundredths of a grain of sulphate of atropia is a dose too small to prevent the occurrence of death after a dose of physostigma one and a half times as large as the minimum lethal, one-fiftieth of a grain is a dose sufficiently large to do so; that doses of sulphate of atropia ranging from one-fiftieth of a grain to four grains and one-tenth are able successfully to counteract this dose of physostigma; and that death occurs when the dose of sulphate of atropia is so large as four grains and three-tenths. In the presence of various causes of fallacy, which cannot altogether be obviated, it is not surprising that results of an exceptional character should occasionally be obtained. The occurrence of death in Experiment 91, where the dose of sulphate of atropia is one-fiftieth of a grain, may legiti-

* Tabular Summary, Series 1, Table 3.

mately be placed among these exceptional results. Several others will afterwards be noted.

Experiments with Twice the Minimum-Lethal Dose of Physostigma.—When atropia was administered five minutes before a dose of physostigma twice as large as the minimum-lethal, the following results were obtained :—*

Experiment **102.**—With 0·19 grain of sulphate of atropia, death occurred.					
Experiment **103.**	„	0·02	„	„	death „
Experiment **104.**	„	0·02	„	„	death „
Experiment **105.**	„	0·021	„	„	death „
Experiment **106-a.**	„	0·025	„	„	recovery „
Experiment **107.**	„	0·03	„	„	death „
Experiment **108-a.**	„	0·04	„	„	recovery „
Experiment **109-a.**	„	0·05	„	„	recovery „
Experiment **110-a.**	„	0·3	„	„	recovery „
Experiment **111-a.**	„	1·	„	„	recovery „
Experiment **112-a.**	„	2·	grains	„	recovery „
Experiment **113-a.**	„	2·3	„	„	recovery „
Experiment **114-a.**	„	3·	„	„	recovery „
Experiment **115-a.**	„	3·2	„	„	recovery „
Experiment **116.**	„	3·3	„	„	death „
Experiment **117.**	„	3·5	„	„	death „

One-fiftieth of a grain of sulphate of atropia is therefore too small a quantity to prevent death from following the administration of a dose of physostigma twice as large as the minimum-lethal, but one-fortieth of a grain is sufficient to do so; and doses ranging from one-fortieth of a grain to three grains and a fifth can successfully antagonise this dose of physostigma. When, however, a dose larger than three grains and a fifth is administered, death occurs. Experiment 107 is another instance of an exceptional result being produced. By referring to the description of this experiment in the Tabular Summary, it will be seen that soon after physostigma had been administered, the rabbit became excited and ran about and struggled energetically. Such movements and struggles appear greatly to favour the toxic action of physostigma; and it has already been pointed out that when they occur, the minimum-lethal dose of physostigma is appreciably lessened.

Experiments with Two and a half times the Minimum-Lethal Dose of Physostigma.—When two and a half times the minimum-lethal dose of physostigma was administered, the following results were obtained :—†

* Tabular Summary, Series 1, Table 4. † Ibid., Table 5.

EXPERIMENT **118.**—With	0·011	grain	of	sulphate	of atropia,	death occurred.
EXPERIMENT **119.**	„ 0·0187	„	„		death	„
EXPERIMENT **120.**	„ 0·025	„	„		death	„
EXPERIMENT **121-a.**	„ 0·025	„	„		recovery	„
EXPERIMENT **122-a.**	„ 0·027	„	„		recovery	„
EXPERIMENT **123-a.**	„ 0·028	„	„		recovery	„
EXPERIMENT **124-a.**	„ 0·034	„	„		recovery	„
EXPERIMENT **125-a.**	„ 0·0375	„	„		recovery	„
EXPERIMENT **126-a.**	„ 0·05	„	„		recovery	„
EXPERIMENT **127-a.**	„ 0·088	„	„		recovery	„
EXPERIMENT **128-a.**	„ 0·43	„	„		recovery	„
EXPERIMENT **129-a.**	„ 0·44	„	„		recovery	„
EXPERIMENT **130-a.**	„ 1·	„	„		recovery	„
EXPERIMENT **131-a.**	„ 1·2	„	„		recovery	„
EXPERIMENT **132-a.**	„ 1·25	„	„		recovery	„
EXPERIMENT **133-a.**	„ 1·63	„	„		recovery	„
EXPERIMENT **134-a.**	„ 2·	„	„		recovery	„
EXPERIMENT **135.**	„ 2·	„	„		death	„
EXPERIMENT **136-a.**	„ 2·2	„	„		recovery	„
EXPERIMENT **137.**	„ 2·3	„	„		death	„
EXPERIMENT **138.**	„ 2·6	„	„		death	„
EXPERIMENT **139.**	„ 2·66	„	„		death	„

The smallest dose of sulphate of atropia that can prevent the occurrence of death after the administration of two and a half times the minimum-lethal dose of physostigma is thus seen to be about one-fortieth of a grain; and it is remarkable that this is also the smallest dose that can prevent the occurrence of death after twice the minimum-lethal dose of physostigma. The experiments likewise show that doses of sulphate of atropia ranging from one-fortieth of a grain to two grains and a fifth are able to prevent the fatal action of two and a half times the minimum-lethal dose of physostigma; and that death occurs if the dose of atropia amount to two grains and three-tenths. In Experiment 135, death occurred with two grains of sulphate of atropia: but I am inclined to look upon this result as exceptional; for in the previous experiment the same dose was followed by recovery, and in the subsequent experiment the larger dose of two grains and a fifth was likewise followed by recovery. Death was probably due to some accidental peculiarity in the condition of the rabbit, by which the general vigour was depreciated.

Experiments with Three times the Minimum-Lethal Dose of Physostigma.—When atropia was administered five minutes before a dose of physostigma

three times as large as the minimum-lethal, the following results were obtained:—*

EXPERIMENT **140.**—With	0·043	grain	of	sulphate of atropia,	death occurred.
EXPERIMENT **141.**	„ 0·05	„	„	death	„
EXPERIMENT **142-a.**	„ 0·06	„	„	recovery	„
EXPERIMENT **143-a.**	„ 0·076	„	„	recovery	„
EXPERIMENT **144-a.**	„ 0·088	„	„	recovery	„
EXPERIMENT **42-a.** †	„ 0·16	„	„	recovery	„
EXPERIMENT **145-a.**	„ 0·5	„	„	recovery	„
EXPERIMENT **146-a.**	„ 1·	„	„	recovery	„
EXPERIMENT **147-a.**	„ 1·2	„	„	recovery	„
EXPERIMENT **148.**	„ 1·3	„	„	death	„
EXPERIMENT **149.**	„ 1·4	„	„	death	„
EXPERIMENT **150.**	„ 1·9	„	„	death	„

These experiments show that while one-twentieth of a grain of sulphate of atropia is insufficient to prevent the occurrence of death after the administration of three times the minimum-lethal dose of physostigma, three-fiftieths of a grain is sufficient to do so. They likewise show that the lethal action of this dose of physostigma may be prevented by any dose of sulphate of atropia from three-fiftieths of a grain to one grain and a fifth; but that if the latter dose be exceeded, the region of successful antagonism is left and death occurs.

Experiments with Three and a half times the Minimum-Lethal Dose of Physostigma.—When the dose of physostigma was three and a half times the minimum lethal, the following results were obtained:—‡

EXPERIMENT **151.**—With	0·044	grain	of	sulphate of atropia,	death occurred.
EXPERIMENT **152.**	„ 0·071	„	„	death	„
EXPERIMENT **153.**§	„ 0·1	„	„	recovery	„
EXPERIMENT **154-a.**	„ 0·2	„	„	recovery	„
EXPERIMENT **155.**	„ 0·3	„	„	death	„
EXPERIMENT **156.**	„ 0·5	„	„	death	„
EXPERIMENT **157.**	„ 1·	„	„	death	„

Accordingly, when the dose of physostigma is so large as three and a half times the minimum-lethal, the range of doses of atropia that can prevent death is a very limited one, extending only from one-tenth to one-fifth of a grain.

* Tabular Summary, Series 1, Table 6.

† A full description of this experiment has already been given in Section A. (see p. 546).

‡ Tabular Summary, Series 1, Table 7.

§ Five days after this experiment, the rabbit became weak and languid; from that time it gradually lost weight and condition; and on the twentieth day, it died. The usual experiment with a dose of physostigma alone could not, therefore, be made.

It has occasionally happened, especially when the subject of the experiment was a young animal, that the atropia effects were unusually slight. If the description in the Tabular Summary of Experiment 152 be compared with that of other experiments in which the same relative dose of atropia was administered, it will be observed that the action of atropia was not developed with its usual prominence, and that, consequently, the physostigma action was only feebly counteracted.

Experiments with Four times the Minimum-Lethal Dose of Physostigma.—When atropia was administered five minutes before a dose of physostigma equivalent to four times the minimum-lethal dose, the following results were obtained:—*

Experiment **158.**—With	0·1	grain	of	sulphate	of atropia,	death occurred.
Experiment **159.**	„ 0·15	„		„	death	„
Experiment **160.**	„ 0·2	„		„	death	„
Experiment **161.**	„ 0·2	„		„	death	„
Experiment **162.**	„ 0·3	„		„	death	„

It was unnecessary to proceed further with these experiments, as it had been rendered obvious by those previously made, that the lethal action of this large dose of physostigma cannot be prevented by atropia, if a dose of this substance between one-tenth and one-fifth of a grain be unable to do so.

It has, accordingly, been shown that the maximum dose of physostigma which can be rendered non-fatal by atropia administered five minutes previously is three and a half times the minimum-lethal dose. It has also been shown that the range of doses of atropia capable of preventing death after the administration of lethal doses of physostigma diminishes as the quantity of physostigma increases.

When these experiments are represented in a diagrammatic form, the results that have been obtained may be clearly and readily appreciated. A simple plan on which to construct a diagram is obviously suggested by the arrangement that has been followed in the description of the experiments. By placing symbolic representations of the results of the experiments performed with each lethal dose of physostigma in horizontal lines, and by arranging these lines so that the doses of physostigma shall succeed each other in regular sequence and at proper intervals, we may obtain a picture which graphically represents the various results that have been mentioned.

Diagram 1 (Plate XXIII.) illustrates the experiments described above, in which atropia was administered five minutes before lethal doses of physostigma. The experiments that terminated in death are represented by crosses, and those

* Tabular Summary, Series 1, Table 8.

that terminated in recovery by dots, while the position assigned to each experiment is determined by the doses of physostigma and atropia which were administered. The doses of atropia are represented by the distance, in a horizontal direction, from the perpendicular line forming the left margin of the diagram, and increase at the rate of one-tenth of a grain for every two subdivisions of the horizontal lines. The doses of physostigma increase from below upwards,—the minimum-lethal dose being represented by the red horizontal line, a dose one and a half times as large as the minimum-lethal by the black horizontal line immediately above the red line, a dose twice as large as the minimum-lethal by the second black horizontal line, and so on until a line is reached at the top of the diagram, which represents a dose of physostigma four times as large as the minimum-lethal. The curved line, *a b c*, separates the fatal experiments (crosses) from those which terminated in recovery (dots); and, accordingly, the blue space on the one side of it represents a region in which death always occurs, and the pink space on the other side a region in which recovery occurs. The doses that were given in any experiment within each of these regions are readily ascertained from the position of the experiment; the dose of physostigma being determined by the horizontal line on which the symbolic representation of the experiment is placed, and that of atropia by the exact spot in the horizontal line which is occupied by the representation.

With these explanations, the results of the experiments will be rendered apparent by a mere glance at the diagram. It may again be pointed out that the more obvious of these results are, that the maximum dose of physostigma which can be rendered non-lethal by atropia administered five minutes previously is about three and a half times the minimum-lethal dose, and that the range of the doses of atropia which are able to render non-fatal various otherwise fatal doses of physostigma, diminishes as the dose of physostigma increases. The general nature of these results is well illustrated in the diagram by the triangular form of the pink region of recovery after lethal doses of physostigma (*a b c*), of which the apex indicates the maximum antagonisable dose of physostigma, and the gradual increase in breadth from the apex to the red horizontal line, the gradual increase in the range of doses of atropia that can prevent the lethal effect of doses of physostigma diminishing from three and a half times the minimum-lethal to the minimum-lethal.

In this diagram, the pink region, and the curved line, *a b c*, have been extended below the red line representing the minimum-lethal dose of physostigma, and therefore into a space where the doses of physostigma are too small of themselves to cause death. The lateral extension of the diagram, however, is insufficient to exhibit the chief interest of this space; but it will be pointed out in the description of the next and only remaining group of experiments connected with the present series.

Experiments with half the Minimum-Lethal Dose of Physostigma.—The considerations which led me to anticipate that the counteracting influence of atropia upon the lethal action of physostigma is successfully exerted only within a definite range of doses, and that death may be produced when a lethal dose of physostigma, which is capable of being rendered non-lethal by atropia, is given in combination with a somewhat large non-lethal dose of atropia, also led me to anticipate that death may be produced by the combined administration of non-lethal doses of the two substances. Experiments were accordingly made,* in which half the minimum-lethal dose of physostigma was administered five minutes after various doses of atropia with the following results :—

Experiment **58**.—With	5·3	grains	of	sulphate of atropia,	recovery occurred.
Experiment **59**.	„ 6·16	„	„	recovery	„
Experiment **60**.	„ 6·2	„	„	recovery	„
Experiment **61**.	„ 6·3	„	„	recovery	„
Experiment **62**.	„ 6·5	„	„	recovery	„
Experiment **63**.	„ 7·	„	„	recovery	„
Experiment **64**.	„ 8·	„	„	recovery	„
Experiment **65**.	„ 8·8	„	„	recovery	„
Experiment **66**.	„ 9·	„	„	recovery	„
Experiment **67**.	„ 9·5	„	„	recovery	„
Experiment **68**.	„ 9·8	„	„	death	„
Experiment **69**.	„ 10·	„	„	death	„
Experiment **70**.	„ 10·5	„	„	death	„

It is shown by these experiments that when sulphate of atropia is administered five minutes before half the minimum-lethal dose of physostigma, death occurs if the dose of the former substance be nine grains and four-fifths, or more. This result appears a very remarkable one, when it is considered that a very decided counteraction is exerted by much smaller doses of atropia against the poisonous action of doses of physostigma greatly in excess of the minimum-lethal, and that the minimum-lethal dose of sulphate of atropia is about twenty-one grains. It, however, merely confirms a legitimate anticipation when certain of the results of the experiments with lethal doses of physostigma are borne in mind. Actions essentially the same as those that are produced in excessive amount when the administration of five grains and three-tenths of sulphate of atropia along with the minimum-lethal dose of physostigma is followed by death, also become excessive after the administration of nine grains and four-fifths of sulphate of atropia along with half the minimum-lethal dose of physostigma. The result may be simply explained by supposing some action or actions of both physostigma and atropia wherein there is no mutual counteraction.

* Tabular Summary, Series i. Table 1.

The effects that are produced by a combination of half the minimum-lethal dose of physostigma with sufficiently varied doses of atropia being thus determined, the entire regions of recovery and of death in the series of experiments in which atropia was administered five minutes before physostigma may now be considered.

This series is completely represented in Diagram 5 (Plate XXIV.), which has been constructed on the same plan as Diagram 1, from which, however, it differs in so far that the increase in the doses of atropia, represented by the distance in a horizontal direction from the perpendicular line forming the left margin of the diagram, proceeds at the rate of one-tenth of a grain for every subdivision of the horizontal lines, in place of for every two subdivisions. This modification was required to curtail the lateral extension of the diagram, so as to retain it within convenient limits.

The area covered by the diagram includes every possible dose of physostigma from the minutest fraction of the minimum-lethal dose to one four times as large as the minimum-lethal, and every possible dose of atropia below the minimum-lethal. In the previous section of this paper, a series of experiments was described which rendered it probable that the minimum-lethal dose of atropia for rabbits is about twenty-one grains for every three pounds weight of animal; and I have specially indicated the position of this dose by a red perpendicular line, which will be seen near the right margin of the diagram.

In the diagram, the region of recovery (pink) appears to be a very restricted one when contrasted with the region of death (blue); and it is almost unnecessary to point out that this relation may be greatly exaggerated by enlarging the diagram so as to include within it a portion of the almost unlimited area in which death occurs after combinations of physostigma and atropia unrepresented in the present diagram. As the region of recovery after lethal doses of physostigma occupies only that portion of the pink space which extends above the red horizontal line, the area that it occupies appears almost insignificantly small. Seeing, however, that a dose of physostigma *three and a half times* as large as the minimum-lethal is included within this region, its insignificance in relation to the entire region of death becomes of but little importance, when the interesting fact of the counteraction of so enormous a dose is realised.

The diagram very clearly displays the singular result, that death may follow the administration of physostigma and atropia in doses both below the minimum-lethal. The combinations that are able to produce this result are included within the blue space below the red horizontal line. The direction of the line separating this space from the subjacent area of recovery (pink) is much more horizontal than that of the line separating the region of death from that of recovery after lethal doses of physostigma. The change of direction

occurs somewhat abruptly at the intersection of the red horizontal line, representing the minimum-lethal dose of physostigma; and it very graphically represents some of the results to which attention has been drawn in the description of the experiments. It was shown by these experiments, that when physostigma is administered in lethal doses, the range of the doses of atropia that are able to produce successful counteraction increases by about one grain for each successive decrease by half the minimum-lethal dose in the dose of physostigma. When, however, physostigma is administered in a dose equivalent only to half the minimum-lethal, the range of doses of atropia that may be given without the occurrence of death is increased beyond the range for the minimum-lethal dose, not by one grain only, but by four grains and three-tenths. Accordingly, while in the region where the doses of physostigma are lethal, the line separating the area of death from that of recovery possesses a direction which indicates an increase of one grain of sulphate of atropia for each decrease by half the minimum-lethal dose in the quantity of physostigma, in the region where the dose of physostigma is less than lethal, it possesses a direction which indicates an increase of about four grains and a half of sulphate of atropia for each decrease by half the minimum-lethal dose in the quantity of physostigma.

II. Determination of the Limits of Antagonism when Atropia is Administered Five minutes after Physostigma.

The second series of experiments was undertaken to determine the limits of successful antagonism when atropia is administered five minutes after physostigma. In the experiments of this series, physostigma was administered in the form of sulphate of the active principle; of which preparation it has already been shown that the minimum-lethal dose is about 0·12 grain per three pounds weight of rabbit. As this dose is the one-tenth of the minimum-lethal dose of extract of physostigma, the experiments of the first series may readily be compared with those of the present.

Experiments with the Minimum-Lethal Dose of Physostigma.—When the minimum-lethal dose of sulphate of physostigmia was administered five minutes before various doses of sulphate of atropia, the results were as follows:—*

Experiment **168.**—With	0·01	grain	of	sulphate	of atropia,	death occurred.
Experiment **169.**	„ 0·015	„		„	death	„
Experiment **170-a.**	„ 0·02	„		„	recovery	„
Experiment **171-a.**	„ 0·05	„		„	recovery	„
Experiment **172-a.**	„ 0·1	„		„	recovery	„
Experiment **173-a.**	„ 0·2	„		„	recovery	„

* Tabular Summary, Series ii. Table 2.

EXPERIMENT **174-a.**—With 0·5 grain of sulphate of atropia				recovery	occurred.
EXPERIMENT **175-a.**	„ 1·	„	„	recovery	„
EXPERIMENT **176-a.**	„ 2· grains	„	„	recovery	„
EXPERIMENT **177-a.**	„ 2·4	„	„	recovery	„
EXPERIMENT **178-a.**	„ 2·5	„	„	recovery	„
EXPERIMENT **179.**	„ 2·6	„	„	death	„
EXPERIMENT **180.**	„ 2·7	„	„	death	„
EXPERIMENT **181.**	„ 2·8	„	„	death	„
EXPERIMENT **182.**	„ 3·	„	„	death	„
EXPERIMENT **183.**	„ 3·2	„	„	death	„
EXPERIMENT **184.**	„ 4·	„	„	death	„

Accordingly, if sulphate of atropia be administered five minutes after the minimum-lethal dose of physostigma, death occurs when the dose of sulphate of atropia is not more than three two-hundredths of a grain, recovery when the dose is from one fiftieth of a grain to two grains and a half, and death again when the dose is larger than two grains and a half. The range of the doses of atropia that can prevent the lethal effect of this quantity of physostigma is, therefore, considerably less when physostigma is administered five minutes before atropia, than when it is administered five minutes after it; and it will be observed that there is a like difference between the results in all the other corresponding groups of experiments in the two series.

Experiments with One and a half times the Minimum-Lethal Dose of Physostigma.—In the next instance, the limits of successful antagonism were determined in the case of a dose of physostigma one and a half times as large as the minimum-lethal :—*

EXPERIMENT **185.**—With 0·03 grain of sulphate of atropia,				death	occurred.
EXPERIMENT **186-a.**	„ 0·05	„	„	recovery	„
EXPERIMENT **187-a.**	„ 0·1	„	„	recovery	„
EXPERIMENT **188-a.**	„ 0·2	„	„	recovery	„
EXPERIMENT **189-a.**	„ 0·3	„	„	recovery	„
EXPERIMENT **190-a.**	„ 0·4	„	„	recovery	„
EXPERIMENT **191-a.**	„ 0·5	„	„	recovery	„
EXPERIMENT **192-a.**	„ 0·7	„	„	recovery	„
EXPERIMENT **193-a.**	„ 1·2	„	„	recovery	„
EXPERIMENT **194-a.**	„ 1·5	„	„	recovery	„
EXPERIMENT **195-a.**	„ 2·0 grains	„	„	recovery	„
EXPERIMENT **196-a.**	„ 2·1	„	„	recovery	„

* Tabular Summary, Series ii. Table 3.

EXPERIMENT **197-a.**—With 2·1 grains of sulphate of atropia, recovery occurred.
EXPERIMENT **198-a.** „ 2·2 „ „ recovery „
EXPERIMENT **199.** „ 2·2 „ „ death „
EXPERIMENT **200.** „ 2·3 „ „ death „
EXPERIMENT **201.** „ 2·4 „ „ death „
EXPERIMENT **202.** „ 2·4 „ „ death „
EXPERIMNNT **203.** „ 2·5 „ „ death „
EXPERIMENT **204.** „ 3·0 „ „ death „

It is shown by these experiments, that when sulphate of atropia is administered five minutes after this dose of physostigma, successful antagonism is produced by any dose of sulphate of atropia ranging from one twentieth of a grain to two grains and one tenth. In Experiment 198–*a.*, successful antagonism likewise followed the administration of two grains and one fifth of sulphate of atropia; but as this result was not obtained in the next experiment, in which the same dose was given, I have not included it within the limits of success.

Experiments with Twice the Minimum-Lethal Dose of Physostigma.—The following results were obtained when atropia was administered five minutes after a dose of physostigma twice as large as the minimum-lethal:—*

EXPERIMENT **205.**—With 0·05 grain of sulphate of atropia, death occurred.
EXPERIMENT **206.** „ 0·08 „ „ death „
EXPERIMENT **207.** „ 0·08 „ „ death „
EXPERIMENT **208.** „ 0·09 „ „ death „
EXPERIMENT **209-a.** „ 0·1 „ „ recovery „
EXPERIMENT **210-a.** „ 0·2 „ „ recovery „
EXPERIMENT **211-a.** „ 0·3 „ „ recovery „
EXPERIMENT **212-a.** „ 0·4 „ „ recovery „
EXPERIMENT **213-a.** „ 0·5 „ „ recovery „
EXPERIMENT **214-a.** „ 0·5 „ „ recovery „
EXPERIMENT **215-a.** „ 0·8 „ „ recovery „
EXPERIMENT **216-a.** „ 0·9 „ „ recovery „
EXPERIMENT **217-a.** „ 1·0 „ „ recovery „
EXPERIMENT **218-a.** „ 1·2 „ „ recovery „
EXPERIMENT **219.** „ 1·3 „ „ death „
EXPERIMENT **220.** „ 1·3 „ „ death „
EXPERIMENT **221.** „ 1·5 „ „ death „
EXPERIMENT **222.** „ 2· grains „ „ death „
EXPERIMENT **223.** „ 2·5 „ „ death „

* Tabular Summary, Series ii. Table 4.

These experiments prove that when sulphate of atropia is administered five minutes subsequently to a dose of physostigma twice as large as the minimum-lethal, nine one-hundredths of a grain of the former substance is too small a dose to prevent death; that doses ranging from one-tenth of a grain to one grain and a fifth are sufficient to do so; and that if the dose be larger than one grain and a fifth, the higher limit of success is passed, and death occurs.

Experiments with Two and a half times the Minimum-Lethal Dose of Physostigma.—The experiments of the next group were made with a dose of physostigma two and a half times as large as the minimum-lethal.* The doses of sulphate of atropia that were given with this dose of physostigma, and the results of the experiments are as follows:—

Experiment **224.**—With	0·05	grain	of	sulphate	of atropia,	death occurred.
Experiment **225.** „	0·08	„	„		death	„
Experiment **226-a.** „	0·1	„	„		recovery	„
Experiment **227-a.** „	0·15	„	„		recovery	„
Experiment **228-a.** „	0·2	„	„		recovery	„
Experiment **229-a.** „	0·3	„	„		recovery	„
Experiment **230-a.** „	0·5	„	„		recovery	„
Experiment **231-a.** „	0·6	„	„		recovery	„
Experiment **232-a.** „	0·7	„	„		recovery	„
Experiment **233-a.** „	0·8	„	„		recovery	„
Experiment **234.** „	0.8	„	„		death	„
Experiment **235.** „	0·9	„	„		death	„
Experiment **236.** „	1·	„	„		death	„
Experiment **237.** „	1·5	„	„		death	„

Accordingly, when two and a half times the minimum-lethal dose of physostigma was given five minutes before sulphate of atropia, the range of doses of the latter substance, capable of producing successful counteraction, extended only from one tenth to about seven tenths of a grain.

Experiments with Three times the Minimum-Lethal Dose of Physostigma.—When the dose of physostigma was three times as large as the minimum-lethal,† the following results were obtained:—

Experiment **238.**—With	0·1	grain	of	sulphate	of atropia,	death occurred.
Experiment **239.** „	0·15	„	„		death	„
Experiment **240-a.** „	0·16	„	„		recovery	„
Experiment **241.** „	0·2	„	„		death	„
Experiment **242.** „	0·25	„	„		death	„

* Tabular Summary, Series ii. Table 5. † *Ibid.*, Table 6.

EXPERIMENT **243.**—With 0·3 grain of sulphate of atropia, death occurred.
EXPERIMENT **244.** „ 0·5 „ „ death „

Recovery, therefore, occurred in only one of the experiments in which atropia was administered five minutes after a dose of physostigma three times as large as the minimum-lethal. The administration of three twentieths and of one fifth of a grain of sulphate of atropia resulted in death, but recovery took place with the intermediate dose of four twenty-fifths of a grain.

Experiments with Three and a half times the Minimum-Lethal Dose of Physostigma.—The results of the previous experiments having made it obvious that the largest dose of physostigma that can be rendered non-lethal by atropia administered five minutes subsequently, is one three times as large as the minimum-lethal, it was evidently unnecessary to perform many experiments with a larger dose. Accordingly, only two such experiments were made, with a dose three and a half times as large as the minimum-lethal;* and the chief purposes of these experiments were to complete this portion of the series, and to ascertain the nature of the phenomena that are produced when this dose of physostigma is given five minutes before atropia.

EXPERIMENT **245.**—With 0·16 grain of sulphate of atropia, death occurred.
EXPERIMENT **246.** „ 0·2 „ „ death „

As both of these experiments terminated fatally, it was needless to continue the series by making experiments with a larger dose of physostigma.

The result of the whole series of experiments is therefore to show that when atropia is administered five minutes after physostigma, the largest quantity of the latter substance that can be rendered non-lethal by the former is three times the minimum-lethal dose, and that the range of the doses of atropia that are capable of preventing the lethal action of physostigma diminishes according as the dose of physostigma is increased.

The results of this series of experiments are illustrated in Diagram 3 (Plate XXIII.), which has been constructed on the same plan and scale as Diagram 1, illustrating the first series of experiments, in order to facilitate a comparison with it. It will be seen that the most prominent of the differences between the two diagrams are, that the region of recovery after lethal doses of physostigma (distinguished as a pink area enclosed within the curved line *a b c*, and the segment *a c* of the red horizontal line) is smaller both in its perpendicular and in its horizontal extent, and that the curved line *a b c* is much more irregular in the diagram of the second series (Diagram 3) than in that of the first (Diagram 1).

The former of these differences very clearly illustrates the greater counter-

* Tabular Summary, Series ii. Table 7.

acting power of atropia when it is administered five minutes before, than when it is administered five minutes after physostigma. It has been shown that in the one case, three and a half times the minimum-lethal dose can be rendered non-fatal, whereas in the other, only three times the minimum-lethal dose can be successfully counteracted; and not only does this difference exist, but the range of the doses of atropia that can prevent the lethal action of any given dose of physostigma is also greater in the former case than in the latter.

The greater irregularity of the curved line *a b c* in Diagram 3 than in Diagram 1 renders very manifest certain other of the results, which also, it is true, have already been mentioned in the description of the experiments, but which cannot be so well appreciated from a mere verbal description as from such a graphic representation as is afforded by the diagrams. It will be remembered that this line separates the experiments that terminated in death from those that terminated in recovery. For convenience of description, it may be regarded as consisting of two portions, *a b* and *b c*,—the former separating the experiments that terminated in recovery after the *smallest* successfully counteracting doses of atropia from those that terminated in death after still smaller doses of atropia, and the latter separating the experiments that terminated in recovery after the *largest* successfully counteracting doses of atropia from those that terminated in death after still larger doses of atropia. In connection with each of these portions of the line *a b c*, there are several points to which attention may be directed.

In Diagram 1, the portion *b c* is a straight line, because, when physostigma is administered five minutes after atropia, the largest doses of atropia that can produce successful counteraction differ from each other by one grain for each difference by half the minimum-lethal dose in the quantity of physostigma. In Diagram 3, however, *b c* is a curved line, because when physostigma is administered five minutes before atropia, the largest successfully counteracting doses of atropia do not diminish regularly as the doses of physostigma are regularly increased.

The greater irregularity of the curved line *a b c* in Diagram 3 than in Diagram 1 is apparent also in the portion *a b*; and it will be seen that this portion has a less perpendicular direction, as well as a less straight course, in the former than in the latter diagram.

In both diagrams, the steep rise of *a b* contrasts in a marked manner with the gradual descent of *b c*. This contrast brings into prominent relief those already mentioned results that show the smallest of the various doses of atropia capable of successfully counteracting different doses of physostigma to differ from each other much less than the largest. It has been ascertained by the first series of experiments, that when atropia is administered five minutes before physostigma, the difference between the smallest

dose of atropia capable of preventing death after the minimum-lethal dose of physostigma and the smallest capable of doing so after a dose three and a half times as large is only nine one-hundredths of a grain, whereas the difference between the largest doses is so great as five grains. When atropia is given five minutes after physostigma, the difference between the smallest dose capable of preventing death after the minimum-lethal dose of physostigma and after a dose three times as large is only thirteen one-hundredths of a grain, whereas the difference between the largest doses is so great as two grains and nine twentieths.

In order more clearly to display the differences between *a b* in the two series of experiments, I have drawn other two diagrams, in which the irregularities of this line are more distinctly shown than in Diagrams 1 and 3. This has been effected by simply diminishing the value of the subdivisions of the horizontal lines, so that each tenth of a grain of sulphate of atropia is indicated by twenty subdivisions in place of by two. By this modification, the direction of the line *a b* has been rendered less perpendicular, and at the same time its course has been more accurately defined. Diagram 2 represents the experiments of the first series, and Diagram 4 those of the second, and only so much of each series has been included as is required to exhibit the course of *a b*. It will be seen that in Diagram 4 the line *a b* is more irregular in its course than in Diagram 2, and that in Diagram 2 a number of irregularities are displayed in this line, which are not apparent in Diagram 1, where the same series of experiments is represented in a more contracted form.

It will likewise be seen from an inspection of the diagrams illustrative of these two series of experiments, that in rabbits a dose of sulphate of atropia equivalent to four twenty-fifths of a grain per three pounds weight of animal is able to prevent the fatal effect of any quantity of physostigma which can be rendered non-fatal by atropia, and that even a very slight modification of this dose suffices to curtail the extent of successful antagonism. There can be little doubt that in every species of animal some dose of atropia occupies a similarly important position, and bears a similar relation to the range of successfully counteracting doses. A result of some practical value has probably been obtained by the establishment of the fact that this dose is much nearer the minimum than the maximum in the range of the doses of atropia capable of preventing the lethal effect of physostigma.

Experiments with half the minimum-lethal dose of physostigma.—The next experiments were made in order to determine the smallest dose of atropia that in conjunction with half the minimum-lethal dose of physostigma administered five minutes before it is sufficient for the production of death.* The following results were obtained:—

* Tabular Summary, Series ii. Table 1.

Experiment **163**.—With	5·	grains	of	sulphate	of atropia,	recovery occurred.
Experiment **164**.	„ 7·	„	„		recovery	„
Experiment **165**.	„ 7·5	„	„		recovery	„
Experiment **166**.	„ 8·	„	„		death	„
Experiment **167**.	„ 8·16	„	„		death	„

The smallest quantity of atropia that in conjunction with half the minimum-lethal dose of physostigma administered five minutes before it is sufficient for the production of death is thus shown to be about eight grains per three pounds weight of rabbit. In the analogous experiments of the first series a similar result was obtained, for although there death did not occur unless the dose of atropia was at least nine grains and four fifths, it is probable that this comparatively slight difference may be due to the physostigma having been given in that series in the form of extract. It will be remembered that the minimum-lethal dose of sulphate of physostigmia is somewhat less than one-tenth of that of extract of physostigma. For convenience of comparison, however, it has been assumed in the second series of experiments, that sulphate of physostigmia is *exactly* ten times as active as extract of physostigma.

With these experiments, the second series is completed. I have not considered it necessary to construct a diagram of the entire series, as all its special characters are displayed in the diagrams representing the experiments in which the doses of physostigma were lethal. With less than lethal doses, the results are so similar to those of the first series of experiments that the region of recovery would be of essentially the same form as that represented in Diagram 5.

III. Determination of the Influence of the interval of Time between the Administration of the two substances, upon the Dose of Atropia required to Counteract a given Dose of Physostigma.

In the two series of experiments that have already been described, the two following series of dose-limits of successful antagonism have been determined, namely, those limits where the atropia is given five minutes before, and those where it is given five minutes after the physostigma. Further, it has been shown that the limits in the one series differ somewhat from those in the other; and when this result is taken in connection with several obvious considerations, it is evident that the series of dose-limits of successful antagonism will be different for every different time-relation in the administration of the two substances. It is, however, evident that to make for each of any considerable number of other time-relations in the administration of the two substances, a complete series of experiments on the plan of the two series already described, would entail an amount of labour quite out of keeping with the value of any results

that might fairly be looked for. The most interesting of such results would be the determination for each case of given doses of the two substances compatible with the production of successful antagonism of the maximum period separating the administration of the one substance from that of the other, both when the atropia is administered before, and when it is administered after the physostigma.

In the experiments of the present series (3d), I have contented myself with determining this period in the case of one constant dose of physostigma with doses of atropia ranging from the one-hundredth of a grain to five grains. When the results derived from this series of experiments are considered along with those of the first and second series, an indication will, I believe, be obtained of the limits in the period separating the administration of the two substances within which successful antagonism may occur, even for the cases where the combination of doses of physostigma and atropia is different from any combination included in the present series.

The dose of physostigma I have selected for these experiments is one equivalent to one and a half times the minimum-lethal dose; and it was administered in the form of sulphate of the active principle, of which preparation this dose is represented by three twenty-fifths of a grain per three pounds weight of rabbit. With each dose of atropia that was given in combination with this dose of physostigma, several experiments were made, which differed from each other by a difference in the interval of time separating the administration of the two substances; this interval being in the first experiments such as to permit of successful antagonism, and being in each subsequent experiment altered until at length it became such as no longer to permit of successful antagonism. This, at least, was the general plan followed in this series, but it was somewhat departed from on several occasions, when the circumstances of the experiments prevented or rendered inconvenient its adoption. Briefly stated, the distinguishing characters of the series were that the dose of physostigma was constant, while the dose of atropia and the interval of time between the administration of the two substances varied.

In certain of the experiments atropia was administered before physostigma, and in others physostigma before atropia; and in order to connect together these two groups of experiments, a third group was undertaken in which atropia and physostigma were administered as nearly simultaneously as possible. In describing the chief results, I shall, as a matter of convenience, in the first place consider (*a*) the experiments in which the two substances were simultaneously administered; then (*b*) the experiments in which atropia was administered after physostigma; and finally (*c*), the experiments in which atropia was administered before physostigma.

(*a*) *Experiments in which Atropia and Physostigma were administered*

simultaneously.—In the experiments of this group,* the administration of the two substances was effected in exactly the same manner as in experiments 44–*a* and 45–*a*, Section A (pp. 553 and 555). Before mentioning the results that were obtained, it is proper to point out that a brief interval necessarily elapsed between the administration of the two substances. This interval, however, was only one of a few seconds, and, practically, was of little moment, especially as uniformity was obtained in all the experiments by care being taken always to inject the dose of atropia before that of physostigma. When, with this precaution, a dose of physostigma one and a half times as large as the minimum-lethal (0·12 grain of sulphate of physostigmia per three pounds weight of rabbit), was administrated nearly at the same moment with various doses of sulphate of atropia, the following results were obtained:—

Experiment **247.**—With	0·02	grain	of sulphate of atropia,	death	occurred.
Experiment **248.** „	0·02	„	„	death	„
Experiment **249–a.** „	0·05	„	„	recovery	„
Experiment **250–a.** „	0·5	„	„	recovery	„
Experiment **251–a.** „	1·	„	„	recovery	„
Experiment **252–a.** „	1·5	„	„	recovery	„
Experiment **253–a.** „	2·	grains „	„	recovery	„
Experiment **254–a.** „	2·5	„	„	recovery	„
Experiment **255–a.** „	3·	„	„	recovery	„
Experiment **256–a.** „	3·3	„	„	recovery	„
Experiment **257.** „	3·5	„	„	death	„
Experiment **258.** „	4·	„	„	death	„
Experiment **259.** „	4·5	„	„	death	„
Experiment **260.** „	5·	„	„	death	„

It is shown by these experiments that when a dose of physostigma one and a half times as large as the minimum-lethal is administered simultaneously with sulphate of atropia, one fiftieth of a grain of the latter substance is a dose insufficient to prevent death, but that one twentieth of a grain is a dose sufficiently large to do so. It is likewise shown that the fatal effect of this dose of physostigma may be prevented when any dose of sulphate of atropia ranging from one twentieth of a grain to three grains and three tenths is given simultaneously with it, and that death occurs when the dose of sulphate of atropia is three grains and a half or greater than this.

(*b*) *Experiments in which Atropia was administered after Physostigma.*—A considerable amount of interest is attached to the experiments of the next group, in which the administration of physostigma preceded that of atropia.† In briefly describing these experiments, I shall, in the first place, consider the

* Tabular Summary, Series iii. Table 1. † Ibid. Table 2.

results obtained when the administration of atropia was effected five minutes after that of physostigma, then, those obtained when the administration of atropia was effected ten minutes after that of physostigma, and so on until a period is arrived at which is too prolonged to permit any dose of atropia to counteract successfully the dose of physostigma invariably administered in this series.

The range of the doses of sulphate of atropia that are able successfully to counteract one and a half times the minimum-lethal dose of sulphate of physostigmia, when the administration of the former substance was effected *five minutes* after that of the latter, has already been ascertained by experiments contained in the second series. It was shown by these experiments (p. 593) that this range extends from the one-twentieth of a grain to two grains and one tenth. Death was found to occur when the dose of sulphate of atropia was so small as three one-hundredths of a grain, and also when it was so large as two grains and three tenths. It will be observed that this range is smaller than that which is obtained when the two substances are simultaneously administered, for in the latter case it extends from the one twentieth of a grain to three grains and three tenths.

In the experiments where the sulphate of atropia was administered *ten minutes* after one and a half times the minimum-lethal dose of sulphate of physostigmia, the following results were obtained:—

EXPERIMENT **261.**—With	0·05	grain	of sulphate of atropia,		death	occurred.
EXPERIMENT **262-a.** „	0·3	„	„		recovery	„
EXPERIMENT **263-a.** „	0·5	„	„		recovery	„
EXPERIMENT **264-a.** „	1·	„	„		recovery	„
EXPERIMENT **265-a.** „	1·5	„	„		recovery	„
EXPERIMENT **266-a.** „	2·	grains	„	„	recovery	„
EXPERIMENT **267-a.** „	2·3		„	„	recovery	„
EXPERIMENT **268-a.** „	2·4		„	„	recovery	„
EXPERIMENT **269-a.** „	2·5		„	„	recovery	„
EXPERIMENT **270.** „	2·7		„	„	death	„
EXPERIMENT **271.** „	3·		„	„	death	„

From these experiments it is seen, that when sulphate of atropia is administered ten minutes after sulphate of physostigmia, any dose of the former substance ranging from three tenths of a grain to two grains and a half, is able to prevent the fatal effect of one and a half times the minimum-lethal dose of the latter substance. The range is, again, a more limited one than that obtained by simultaneous administration. It is, however, a somewhat more extended one than that obtained where the atropia is administered five minutes after the physostigma, and the greater extension is due to the maximum successfully antagonising dose of sulphate of atropia being considerably greater when the administration

of atropia succeeds that of physostigma by ten minutes, than when it succeeds it by only five minutes. This difference is one, certainly, which I did not anticipate. My expectation was rather that the maximum successfully antagonising dose of sulphate of atropia would be greater when the interval was one of five minutes, than when it was one of ten minutes. It is difficult to account for the result that has been obtained. I cannot attribute it to any known cause of fallacy in the circumstances of the experiments; and the explanation that it is simply due to some of the causes of fallacy that are unavoidable in such a research, seems to be opposed by its being derived, not from one or two experiments only, but from seven, of which four belong to the interval of five minutes, and three to that of ten minutes. Of the experiments belonging to the former interval, death occurred in one where the dose of sulphate of atropia was 2·3 grains, in two where it was 2·4 grains, and in one where it was 2·5 grains; while of the experiments belonging to the latter interval, recovery occurred in one with each of these doses. Further, of these experiments, two differing in the interval but agreeing in the dose of sulphate of atropia (2·4 grains) were performed on the same day, on rabbits of nearly the same weight, and as far as could be judged, of equally healthy condition, and yet, as has already been stated, death occurred in the experiment with the former interval (Experiment 202), and recovery in that with the latter interval (Experiment 268–*a*).

Still, notwithstanding these various circumstances, it may be that the result is due to a mere accident. If, however, it be not so, its occurrence may possibly be explained by supposing that the non-antagonised action or actions of physostigma produce their maximum effect after a greater interval of time from the administration than is the case with atropia. If this be assumed, it is obvious that death will be most easily produced when the administration of the two substances is so timed that the two maxima of effect may coincide. These various suppositions being granted, the apparently anomalous result of a larger dose of sulphate of atropia being within the range of successful antagonism when the interval is one of ten minutes than when it is one of five minutes, may be accounted for, by assuming that certain actions produced by the two substances are not present in so great a degree of combined intensity when atropia is given ten minutes after physostigma as when it is given only five minutes after it.

Passing now to the experiments in which the interval of time was greater than ten minutes, I find that only one experiment was made in which atropia was administered *fourteen minutes* after physostigma (Experiment 272–*a*). In this experiment, the dose of sulphate of atropia was three tenths of a grain, and with it the fatal effect of one and a half times the minimum-lethal dose of physostigma was successfully antagonised.

Several experiments, however, were made in which the administration of the atropia was effected *fifteen minutes* after that of the physostigma. Their results are as follows:—

EXPERIMENT **273-a.**—With 0·3 grain of sulphate of atropia, recovery occurred.
EXPERIMENT **274-a.** „ 0·5 „ „ recovery „
EXPERIMENT **275-a.** „ 1· „ „ recovery „
EXPERIMENT **276.** „ 1·5 „ „ death „
EXPERIMENT **277.** „ 2· grains „ „ death „

With this interval, therefore, death is prevented from occurring by doses of sulphate of atropia ranging from three tenths of a grain to one grain. It will be observed that the range is a more limited one than that which was obtained when the two substances were simultaneously administered, and also when the interval was less than fifteen minutes. It is, however, very satisfactory to find, as an indication of the remarkable efficacy of the antagonising influence of atropia, that even when one and a half times the minimum-lethal dose of physostigma is allowed to exert its toxic power without any interference for so long a period as fifteen minutes, the administration of atropia is still able to prevent death. The details of the experiments are of so great interest that I regret that it is inadvisable to describe them fully,—since this could not be done without greatly increasing the already formidable dimensions of this communication. I must therefore content myself with referring to the abridged accounts contained in the Tabular Summary. In all of the experiments, the animal was at the point of death before the atropia was administered, and yet, in two or three minutes threreafter, the gravity of the symptoms lessened with the most extraordinary rapidity, not only in those experiments where perfect recovery was ultimately effected, but even in those where the final result was death. On several occasions also, an experiment that had been commenced could not be completed, because death occurred in less than fifteen minutes after the administration of physostigma, and, therefore, before the proper time had arrived for the administration of atropia.

When, indeed, the interval was greater than fifteen minutes, some difficulty was experienced in obtaining any evidence whatever of the influence that is exerted by atropia upon the toxic effect of this dose of physostigma. It was only after several attempts, that I succeeded in performing the two following experiments, in which atropia was administered *seventeen minutes* after one and a half times the minimum-lethal dose of physostigma.

EXPERIMENT **278.**—With 0·3 grain of sulphate of atropia, death occurred.
EXPERIMENT **279.** „ 0·5 „ „ death „

In both experiments, death occurred: in the one, after the administration

of three tenths of a grain of sulphate of atropia; in the other, after the administration of half a grain.

From the experiments of this group we learn that the fatal effect of one and a half times the minimum-lethal dose of physostigma can be prevented by any dose between one-twentieth of a grain and two grains and one tenth of sulphate of atropia, if it be administered within five minutes afterwards; by any dose between three tenths of a grain and two grains and one tenth of sulphate of atropia, if it be administered within ten minutes afterwards; and by any dose between three tenths of a grain and one grain of sulphate of atropia, if it be administered within fifteen minutes afterwards.

(*c*) *Experiments in which Atropia was administered before Physostigma.*—In the last group of experiments to be considered, the administration of atropia preceded that of physostigma.* I shall, in the first place, describe those experiments that were undertaken for the purpose of determining what range of doses of atropia can successfully counteract one and a half times the minimum-lethal dose of physostigma, when the former substance is given five minutes before the latter. In Series ii. of this section, this range has already been determined in the case of the extract of physostigma; but it was considered advisable also to perform with the sulphate of physostigmia a few experiments in which this interval was observed, as it has been shown that the dose of this substance adopted as the minimum-lethal is somewhat more powerful than the dose of extract of physostigma adopted as such (p. 543).

Experiments were accordingly performed, in which atropia in various doses was administered *five minutes* before one and a half times the minimum-lethal dose of sulphate of physostigmia. The doses of atropia given in each experiment, and the results obtained, were as follows:—

Experiment **280.**	—With 0·01 grain	of sulphate of atropia,	death	occurred.
Experiment **281-a.**	„ 0·02	„ „	recovery	„
Experiment **282-a.**	„ 0·05	„ „	recovery	„
Experiment **283-a.**	„ 3·5 grains	„ „	recovery	„
Experiment **284-a.**	„ 3·7	„ „	recovery	„
Experiment **285.**	„ 3·9	„ „	death	„
Experiment **286.**	„ 4·0	„ „	death	„
Experiment **287.**	„ 4·3	„ „	death	„
Experiment **288.**	„ 4·5	„ „	death	„
Experiment **289.**	„ 5·	„ „	death	„

It is shown by these experiments that when sulphate of atropia is administered five minutes before one and a half times the minimum-lethal dose of sulphate of physostigmia, any dose of the former substance ranging from one fiftieth of a grain to three grains and seven tenths is able to produce success-

* Tabular Summary, Series iii. Table 3.

ful counteraction. The smallest of these doses of sulphate of atropia is exactly the same as that which can successfully counteract one and a half times the minimum-lethal dose of extract. The largest, however, is smaller by two fifths of a grain than the largest dose that can successfully counteract one and a half times the minimum-lethal dose of the extract; and this difference, as tending to show that the dose of sulphate of physostigmia adopted as the minimum-lethal is somewhat more powerful than the dose of extract adopted as such, confirms the result of the experiments by which the minimum-lethal dose of these two preparations of physostigma was determined.

In the description of the other experiments of this group, those performed with each of the doses of sulphate of atropia administered will be separately considered, commencing with the smallest dose that was given. The experiments made with each dose of sulphate of atropia will be briefly described in an order proceeding from the shortest to the longest interval of time that separated the administration of the two substances. In the account of these experiments, the interval of time, the dose of sulphate of atropia, and the result of the experiments, will alone be mentioned.

The smallest dose of sulphate of atropia that was given at various intervals before one and a half times the minimum-lethal dose of sulphate of physostigmia, was *one twentieth of a grain* (0·05 gr.); and with this dose the following experiments were performed :—

Experiment **290-a.**—With an interval of 10 minutes, recovery occurred.					
Experiment **291-a.**	,,	15	,,	recovery	,,
Experiment **292-a.**	,,	20	,,	recovery	,,
Experiment **293.**	,,	25	,,	death	,,
Experiment **294.**	,,	30	,,	death	,,

These experiments show that the administration of one twentieth of a grain of sulphate of atropia may precede that of one and a half times the minimum-lethal dose of physostigma by an interval of twenty minutes, or less, and still successful antagonism will occur. If, however, this interval be prolonged beyond twenty minutes, as to twenty-five or thirty minutes, successful antagonism does not occur.

In the next experiments, the dose of sulphate of atropia was *half a grain* (0·5 gr.); and the intervals that elapsed between its administration and the subsequent administration of one and a half times the minimum-lethal dose of physostigma, as well as the results of the experiments, were as follows :—

Experiment **295-a.**—With an interval of 15 minutes, recovery occurred.					
Experiment **296-a.**	,,	25	,,	recovery	,,
Experiment **297-a.**	,,	30	,,	recovery	,,

EXPERIMENT **298.**—With an interval of 35 minutes, death occurred.
EXPERIMENT **299.** „ 40 „ death „

It appears, therefore, that successful antagonism occurs when half a grain of sulphate of atropia is administered thirty minutes, or less, before one and a half times the minimum-lethal dose of physostigma but not when the interval is one of thirty-five minutes, or more.

The next dose of sulphate of atropia with which experiments of this kind were made was *one grain and a half* (1·5 gr.). The intervals of time that elapsed before the administration of physostigma and the results obtained were the following :—

EXPERIMENT **300-a.**—With an interval of 15 minutes, recovery occurred.
EXPERIMENT **301-a.** „ 30 „ recovery „
EXPERIMENT **302-a.** „ 40 „ recovery „
EXPERIMENT **303-a.** „ 60 „ recovery „
EXPERIMENT **304-a.** „ 65 „ recovery „
EXPERIMENT **305.** „ 70 „ death „
EXPERIMENT **306.** „ 80 „ death „

Accordingly, the longest interval compatible with the production of successful antagonism that may elapse after the administration of one grain and a half of sulphate of atropia, and before that of one and a half times the minimum-lethal dose of physostigma, is one of about sixty-five minutes.

I have next to describe, in a similarly abridged manner, a number of experiments in which the dose of sulphate of atropia was *three grains.*

EXPERIMENT **307-a.**—With an interval of 40 minutes, recovery occurred.
EXPERIMENT **308-a.** „ 65 „ recovery „
EXPERIMENT **309-a.** „ 90 „ recovery „
EXPERIMENT **310-a.** „ 95 „ recovery „
EXPERIMENT **311.** „ 100 „ death „
EXPERIMENT **312.** „ 105 „ death „
EXPERIMENT **313.** „ 120 „ death „

It is shown by these experiments that successful antagonism occurs when a dose of three grains of sulphate of atropia is administered ninety-five minutes (one hour and thirty-five minutes), or at any shorter period, before one and a half times the minimum-lethal dose of physostigma ; but that it does not occur when the period is prolonged to one hundred minutes, or still further.

The doses of sulphate of atropia that were given in the four sets of experiments of this group that have last been described, namely, 0·05 gr., 0·5 gr., 1·5 gr., and 3 grs., are all included within the range of the doses of this substance able to prevent the fatal effect of one and a half times the minimum-lethal dose of

sulphate of physostigmia both when the atropia is administered five minutes before the physostigma, and when the two substances are simultaneously administered. The dose with which the last-mentioned experiments were performed, namely, three grains, is, however, near the maximum limit of the range in the case of simultaneous administration, and, accordingly, not far from this limit in the case where atropia is administered five minutes before physostigma.

I have in the next place to describe two sets of experiments made respectively with one and the other of two doses of sulphate of atropia greater not only than the maximum dose that produces successful antagonism when given simultaneously with one and a half times the minimum-lethal dose of physostigma, but also than the maximum that does so when given five minutes before it.

The first of these doses of sulphate of atropia is *four grains and a half*. It was administered before physostigma at the intervals and with the results that will now be stated :—

Experiment **314**.—With an interval of	10	minutes,	death	occurred.
Experiment **315-a**. „	15	„	recovery	„
Experiment **316-a**. „	15	„	recovery	„
Experiment **317-a**. „	20	„	recovery	„

The very interesting and remarkable character of the results of these experiments becomes apparent when they are considered along with those of two experiments previously described, in which the same doses of sulphate of atropia and sulphate of physostigmia respectively were administered. In the first of these (Experiment 259), the administration of the two substances was simultaneously effected, and in the second (Experiment 288), the atropia was administered five minutes before the physostigma; and in both cases death occurred. It has *now* been shown that when, with the same respective doses, the atropia is given ten minutes before the physostigma, the result is *still* a fatal one; but that when the atropia is given fifteen or twenty minutes before the physostigma, recovery, and not death, occurs.

I have not made any experiments with this dose of sulphate of atropia for the purpose of determining the maximum interval of time that may, without hindering the production of successful antagonism, be allowed to intervene between its administration and the subsequent administration of one and a half times the minimum-lethal dose of sulphate of physostigmia.

Such a determination, however, was accomplished in the experiments where the dose of sulphate of atropia was *five grains*. The intervals of time separating the administration of the two substances, and the results obtained in these experiments, were as follows :—

EXPERIMENT **318.**—With an interval of	15	minutes,	death	occurred.	
EXPERIMENT **319.**	„	20	„	death	„
EXPERIMENT **320-a.**	„	25	„	recovery	„
EXPERIMENT **321-a.**	„	30	„	recovery	„
EXPERIMENT **322-a.**	„	65	„	recovery	„
EXPERIMENT **323.**	„	65	„	death	„
EXPERIMENT **324.**	„	105	„	death	„
EXPERIMENT **325-a.**	„	105	„	recovery	„
EXPERIMENT **326-a.**	„	140	„	recovery	„
EXPERIMENT **327-a.**	„	170	„	recovery	„
EXPERIMENT **328-a.**	„	175	„	recovery	„
EXPERIMENT **329.**	„	180	„	death	„
EXPERIMENT **330.**	„	185	„	death	„
EXPERIMENT **331.**	„	200	„	death	„

It appears from these experiments, that when a dose of five grains of sulphate of atropia is administered before one and a half times the minimum-lethal dose of sulphate of physostigmia, death occurs if the interval of time be one of fifteen minutes, or of twenty minutes; that recovery generally occurs if the interval be one included within the wide limits extending from twenty-five minutes to one hundred and seventy-five minutes (two hours and fifty-five minutes); and that death again occurs if the interval be one so great as a hundred and eighty minutes (three hours). In connection with these results also, it is of interest to point out that in two experiments previously described, where the same respective doses of sulphate of atropia and sulphate of physostigmia were given, death occurred both when the two substances were simultaneously administered (Experiment 260) and when the atropia was administered five minutes before the physostigma (Experiment 289).

A very interesting and suggestive chain of events is therefore presented by the experiments in which five grains of sulphate of atropia was administered in combination with one and a half times the minimum-lethal dose of sulphate of physostigmia. For it is seen that certain actions produced with sufficient intensity to cause death when the two substances are simultaneously administered, lose the power of doing so when the atropia is administered at an interval of twenty-five minutes before the physostigma; while the now unobscured counteraction of the lethal effect of this dose of physostigma, which makes this loss perceptible, persists till the interval is increased to three hours.

These various changes are no doubt caused by there being a progressive increase followed by a decrease in the intensity of certain of the actions that are produced by this dose of atropia. The progressive increase is probably influenced to some extent by the rate at which the atropia is

absorbed. The decrease may be referred to various causes, such as the elimination of the atropia, or its destruction in the tissues, or it may be due merely to a diminution in the degree of the actions produced by this substance, altogether independent of either elimination or destruction.

To whatever cause we refer the decrease in intensity of the actions of atropia, in some exceptional circumstances, connected in all probability with the condition of the animal employed in the experiment, a delay seems to occur in the rapidity with which those actions are decreased, that are accountable for the production of death when the interval by which the administration of the atropia precedes that of the physostigma is one of twenty minutes, or one of shorter duration. The occurrence of this delay is well illustrated by the fatal termination of Experiments 323 and 324; in the first of which the atropia was administered sixty-five minutes, and in the other one hundred and five minutes before the physostigma. In both experiments, the symptoms that were observed closely resemble those of the experiments in which an interval too brief for the production of successful antagonism had separated the administration of the two substances. A reference to the description of these experiments in the Tabular Summary will confirm this statement.

The various results of this, the third series of experiments, have been graphically represented in Diagram 6 (Plate XXV.). This diagram agrees with the diagrams already described in showing by distance from one and the other of two straight lines placed at right angles to one another, what amount of one and the other respectively of two variables is present in each of certain combinations of them further diagrammatically distinguished by the character of the mark indicating their diagrammatic position into fatal and non-fatal: and differs from them in substituting for one of their variables, namely, the dose of physostigma, a new variable, namely, a varying interval of time separating the administration of the one substance from that of the other; the difference depending on the fact, that while in the two previous series of experiments the dose of atropia and the dose of physostigma varied, and the interval of time separating the administration of the one substance from that of the other was constant, in the present series the dose of atropia and the interval of time separating the administration of the one substance from that of the other varied, and the dose of physostigma was constant.

The representation of the *order* in which the administration of the one substance stands to that of the other, is provided for by the arrangement that in the representation of length of interval of time by distance from the line of zero interval, that distance is taken on the upper or on the under side respectively of that horizontal line, according as the administration of the atropia precedes or follows that of the physostigma. Each of the equal subdivisions of distance from the line of zero interval, which aremarked out by the lines drawn parallel

to that line, represents five minutes ; and each of those of distance to the right from the perpendicular line forming the left margin of the diagram, which are marked out by the lines drawn parallel to that line, represents (as in Diagrams 1 and 3) a twentieth of a grain of sulphate of atropia. The constant dose of physostigma was one and a half times the minimum-lethal one.

The conditions of each experiment may, therefore, at once be apprehended from the position occupied by the representation of the experiment in the diagram : whether atropia was administered before or after physostigma is seen from the representation of the experiment being placed above or below the zero line ; what the interval of time separating the administration of the two substances was, from the distance of this representation in a perpendicular direction from the zero line of time ; and what dose of sulphate of atropia was administered, from the distance of this representation in a horizontal direction from the left margin of the diagram.

In this diagram, as in the others as yet described, the experiments that terminated in recovery (dots) have been separated from those that terminated in death (crosses) by a black line ; and the regions of recovery and death that are thereby mapped out have been coloured respectively pink and blue.

When the diagram is examined, the two points to which attention will probably be attracted first are the irregular form of the region of recovery (pink), and the much greater extent, both horizontal and perpendicular, of the portion of this region where atropia was administered before physostigma than of the portion where atropia was administered after physostigma. The existence of this difference illustrates very distinctly a general result of the experiments of this series, namely, that successful antagonism occurs with a greater range of doses of atropia and with a greater range of intervals of time between the two administrations, when atropia is given before physostigma, than when it is given after it. In the latter case, the length of the intervals of time is obviously limited by there being a limitation to the time within which this dose of physostigma itself produces death. In the former case, the intervals are not subject to a similar curtailment, seeing that the doses of atropia represented in the diagram are all considerably below the minimum-lethal dose.

In reference to the irregularity in the form of the region of recovery, the only special point to which attention need be drawn, is the existence of the curious anomaly in the portion where atropia was administered after physostigma. This anomaly brings into almost too great prominence the fact, already at some length considered, that the maximum dose of atropia that produces successful antagonism with the dose of physostigma employed in this series was found to be greater when the latter substance is administered ten minutes before the atropia than when it is administered only five minutes before it. It has already been shown that the existence of this seemingly anomalous result is

founded on the evidence of a sufficiently large number of trustworthy experiments to prevent its being regarded as certainly due to some of those unavoidable variations in the conditions of the experiments that we do not at present know how to make allowance for, although this is the explanation that is most naturally suggested.

Soon after presenting this anomaly, the line of demarcation between the two regions crosses the line representing simultaneous administration, and then continues its gradual ascent until it reaches the right margin of the diagram. In this course, there are indicated certain points of interest relating to the maximum dose of atropia that produces successful antagonism at different intervals of time. It is seen that this maximum dose is considerably smaller when atropia is administered after physostigma than when the two substances are simultaneously administered; that is also smaller, though by a less difference than in the previous instance, when the two substances are simultaneously administered, than when atropia is administered five minutes before physostigma; and finally, that it augments in size with each increase of the interval of time separating the administration of atropia from the subsequent administration of physostigma. So that, as I have already pointed out, when such a dose of sulphate of atropia as five grains is used, death occurs when it is administered at any interval after the physostigma, simultaneously with it, or at any interval less than twenty minutes before it; but, on the other hand, recovery generally occurs when it is given at any interval from twenty-five to one hundred and seventy-five minutes before it.

The portion of the line of demarcation that forms the upper boundary of the region of recovery rises gradually and at a tolerably uniform rate from where it cuts the perpendicular line indicating a twentieth of a grain of sulphate of atropia to where it reaches that indicating five grains; and as this rise implies a corresponding increase in the interval of time by which the administration of atropia preceded that of physostigma, it displays very clearly another general result of the experiments, namely, the establishment of the fact that the maximum interval of time by which the administration of atropia may compatibly with the production of successful antagonism precede that of physostigma—in other words, the length of time the antidotal influence produced by the administration of a dose of atropia lasts—gradually and with tolerable regularity increases as the dose of atropia is augmented from one-twentieth of a grain to five grains. How far increase of that interval goes on in the case of further increase of the dose of atropia, has not been tested by experiment; but it seems likely that were this done, it would be found to stop at a dose of atropia somewhere between the largest already tested (five grains) and the minimum-lethal (about twenty-one grains). Near this point, the portion of the line of demarcation forming the upper boundary of the region of recovery will reach its highest

elevation (an elevation above that represented in the diagram), and either there or somewhere further in advance, it will meet the portion of the line forming the lower boundary of this region, and in this manner the boundaries of the region of recovery would be completed.

General Characters of the Symptoms produced by different Combinations of Atropia and Physostigma.—In the account that has been given of the experiments contained in this section, I have avoided all details of the nature of the symptoms that were produced, believing that any special allusion to them would probably have distracted the attention from the primary purpose of this portion of the research. Further, the minute details of the kind that in the previous section were in many instances given were not concerned with experiments performed at any special portions of the region of recovery, nor in any instance with experiments performed in the region of death. The experiments in each of these regions may be divided into two great classes, in accordance with the symptoms which they presented. In the one class, certain of the effects of atropia were prominently developed and maintained for considerable intervals, while the effects of physostigma were but slightly, or even not at all exhibited. In the other class, several of the effects of physostigma were present in a decided form, and masked either completely or in part the effects of atropia.

In the *first* and *second* series, the former class of symptoms characterised the experiments where recovery followed the administration of a large dose of atropia, and also those where death followed the administration of an excessive dose of this substance. The latter class of symptoms were present in the experiments where recovery followed the administration of a small dose of atropia, and also in those where death followed the administration of a dose of atropia insufficient to counteract successfully the lethal effect of the dose of physostigma given in combination with it.

In the *third* series, after both substances had been administered, atropia effects were most distinctly produced in the experiments where recovery followed the administration of a large dose of sulphate of atropia simultaneously with, or five or ten minutes after the dose of physostigma there given; and also in those where recovery followed the administration of the larger of the doses of sulphate of atropia that were given before this dose of physostigma, provided the interval of time separating the administration of the two substances were not a very prolonged one. These effects were likewise prominently displayed in the experiments where death followed the administration of an excessive dose of sulphate of atropia simultaneously with, or five or ten minutes after, the physostigma; and also in those where death followed the administration of from 3·9 to 5 grains of sulphate of atropia before the physostigma at an interval of time too short to permit of successful antagonism. On the other hand, the effects of physostigma were in this series most prominently

developed in the experiments where recovery followed the administration of the smaller of the doses of sulphate of atropia that were given simultaneously with, after, and before the dose of physostigma, or of a large dose of sulphate of atropia at a long interval of time before the physostigma. These effects were also produced in a marked form when death followed the administration of the smaller of the doses of sulphate of atropia that were given simultaneously with, and five minutes after and before the dose of physostigma, and when death occurred where sulphate of atropia in somewhat large doses was given before physostigma at too prolonged an interval of time to admit of successful antagonism.

Such, in general terms, were the characters of the symptoms in different portions of the regions of recovery and death. The data for a more complete analysis of these symptoms are contained in the Tabular Summary: in this very general analysis, I have, with regard to the region of recovery, contented myself with showing that the symptoms produced when atropia successfully counteracts the lethal effect of physostigma vary greatly, according to the conditions of administration. Successful antagonism is not necessarily accompanied with any special class of symptoms. It may be attended by a greater prominence of the effects of atropia, but the same is true also of those of physostigma. And, further, it does not appear that any special action belonging to one or other substance requires to be obviously or prominently produced, in order that the antagonism shall be successful.

It is almost unnecessary to add, that the experiments in which recovery occurred differed much from each other in the severity of their symptoms. In many experiments the animal was only slightly affected, and there was no reason at any time to anticipate a fatal result; in others, however, symptoms of a very serious character were developed, and in several cases it was for a long time a matter of doubt whether the animal would recover.

Combined Representation of the Three Series of Experiments.—In the three series of experiments that have now been described, I have demonstrated the limits of antagonism between atropia and physostigma,—firstly, when atropia is administered five minutes before physostigma; secondly, when atropia is administered five minutes after physostigma; and thirdly, when atropia in various doses is administered at various intervals of time before and after one and a half times the minimum-lethal dose of physostigma.

In each series of experiments, of the three quantities (namely, dose of physostigma, dose of atropia, and interval of time between the administration of the substances) only two vary, and the results of any one series may therefore be represented by a diagram constructed on a plane. Such diagrams have been constructed, and were described when the several series of experiments were being separately considered.

A combined representation of the results of the three series, involving, as it must, three variable quantities, will be best effected by means of a model in three dimensions. Such a model may be constructed by bending wires into the shape of the plane curves separating the pink and blue regions of Diagrams 1, 3, and 6, and fixing them in the manner to be described to two boards placed at right angles to one another. The wire of Diagram 1 may be called *a*, that of Diagram 3 *b*, and that of Diagram 6 *c*, and the boards may be distinguished as A and B. Wire *a* is to be so fixed to the boards that its plane shall be at right angles to both of them, and intersect A in the position of the left-hand margin, and B in that of the lower margin of Diagram 1. Wire *b* is to be so fixed to the boards that its plane shall be parallel to, and at a distance corresponding to an interval of ten minutes from that of *a*, and intersect A in the position of the left-hand margin, and B in that of the lower margin of Diagram 3. Lastly, wire *c* is to be so attached to wires *a* and *b*, that its plane shall be parallel to, and at a distance corresponding to one and a half times the minimum-lethal dose of physostigma from B, and intersect A in the position of the left-hand margin of Diagram 6 and a plane parallel to and half way between the planes of *a* and *b*, which may be called plane C, in the position of the line of simultaneous administration.

The conditions represented by any point in the model may be found by drawing from it perpendiculars to the planes A, B and C. The perpendicular upon A represents the dose of atropia; that upon B the dose of physostigma; and that upon C the interval of time between the administration of the two doses, atropia being administered first where the point is on the one side, and physostigma first when it is on the other side of the plane C.

Diagram 7 is an orthogonal projection of such a model, in which the three variables are represented on a scale somewhat different from that of Diagrams 1, 3, and 6; but this difference does not cause any difficulty in the recognition of the corresponding parts. The continuous line *a a′* represents the boundary of the region of recovery in the experiments where atropia was administered five minutes *before* physostigma (Series 1); the continuous line *b b′* the boundary of this region where atropia was administered five minutes *after* physostigma (Series 2); and the dotted line *c a′ b′ b a d* the boundary of this region where atropia was administered in various doses and at various intervals of time before and after one and a half times the minimum-lethal dose of physostigma (Series 3). It is obvious that these lines lie upon a curved surface, on whose one side every point represents conditions leading to death, and on whose other side every point represents conditions leading to recovery. The surface, of course, cannot be fully known from the three sections of it that have been obtained by these experiments. It could be known only by greatly increasing the number of the experiments, so as to obtain a number of other curves of

perpendicular sections parallel to and on either side of $b\ b'$ and $a\ a'$, and of horizontal sections parallel to and below and above $c\ a'\ b'\ b\ a\ d$. To obtain a

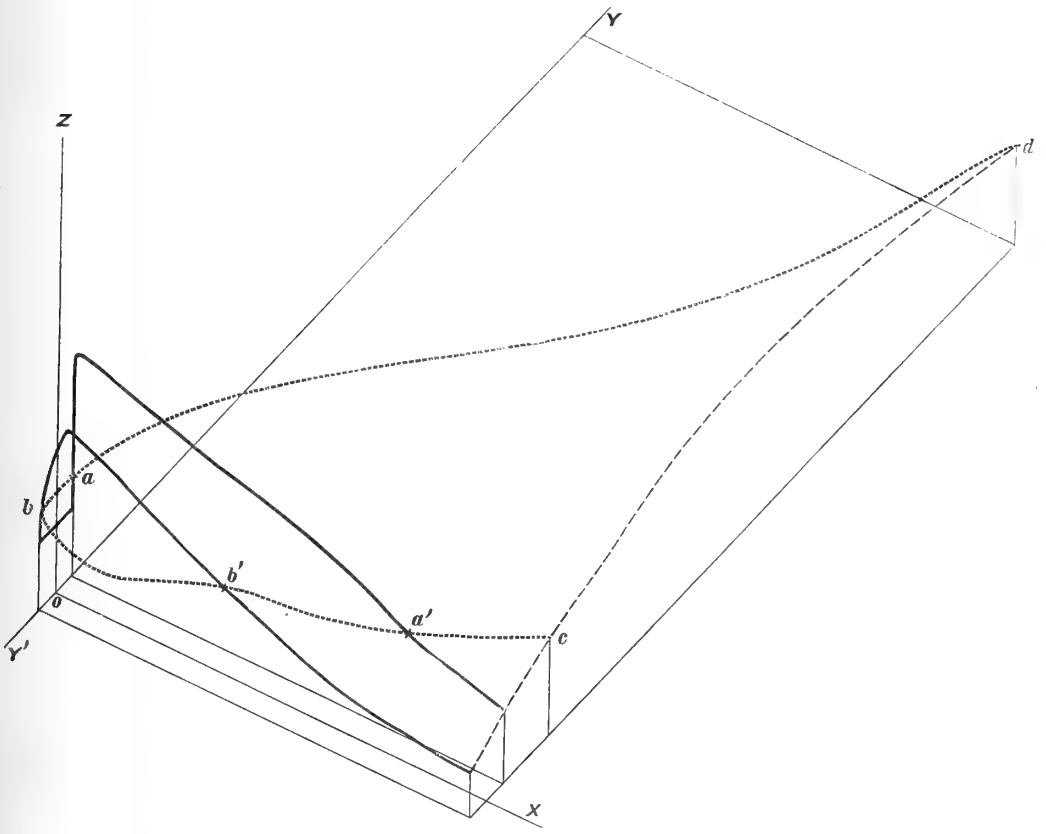

Diagram 7.

This woodcut is an orthogonal projection of a model in which the curves separating the regions of recovery and death in the three series of experiments are brought into proper relationship to each other. The curve of the first series of experiments is represented by $a\ a'$, that of the second series by $b\ b'$, and that of the third series by $c\ a'\ b'\ b\ a\ d$. Doses of physostigma are indicated by the distance (parallel to the axis of z) from the plane Y O X ; doses of atropia, by the distance (parallel to the axis of x) from the plane Z O Y ; and intervals of time between the administration of the two substances, by the distance (parallel to the axis of y) from the plane Z O X, points on the Y side of this plane indicating atropia administered *before* physostigma, and points on the Y′ side indicating atropia administered *after* physostigma. The curve $c\ a'\ b'\ b\ a\ d$ intersects the curve $a\ a'$ at a' and a, and the curve $b\ b'$ at b' and b; the points a' and a indicating the positions respectively of the largest and the smallest doses of sulphate of atropia that produce successful antagonism when administered five minutes *before* one and a-half times the minimum-lethal dose of physostigma, and the points $b'\ b$ the positions respectively of the largest and smallest doses of sulphate of atropia that produce successful antagonism when administered five minutes *after* this dose of physostigma.

In this diagram, the line $c\ a'\ b'\ b\ a\ d$ has been drawn without taking into account the apparently anomalous experiments already discussed in page 602. The interrupted line $c\ d$ occupies the supposed position of a line that would represent the results of a series of experiments in which a fixed dose of sulphate of atropia (5 grains per three pounds weight of animal), and varying doses of physostigma were administered at varying intervals of time. Such a series of experiments has not been made, but the points of intersection of this line with the lines $b\ b'$, $a\ a'$, and $c\ a'\ b'\ b\ a\ d$ are fixed by the position of the latter lines.

I am indebted to my friend Professor Crum Brown for the drawing from which this woodcut has been made, as well as for many valuable suggestions relative to the preparation of the other diagrams in this paper.

sufficient number of such curves, however, the labour and expenditure of time would be very great, seeing that so large a number of experiments as two hundred and seventy-six were made in order to obtain the curves represented in the diagram. Besides, a tolerably accurate conception of the form of the curved surface may be gained from the curves of the three series of experiments that have been made.

In all probability the summit of this curved surface does not occupy an elevation materially above that of the apex of the curve *a a'*; but if it reach a higher elevation, the highest point will probably be situated at only a short distance behind that apex. From the highest point the surface slopes gradually to *d c*, somewhat steeply to *a' b'*, with decided steepness to *b' b*, and with still greater steepness to *b a*.

The region included within this curved surface represents every possible variation in the doses of atropia and physostigma and in the intervals of time separating the administration of the two substances that is compatible with the production of successful antagonism between physostigma and atropia.

General Summary.—Although the above combined representation of the three series of experiments in reality presents a complete summary of the more important of the results that have been obtained, it may be convenient to briefly recapitulate these results. At page 540, I have stated that the chief objects of the research are to show that atropia possesses in a remarkable degree the power of counteracting the lethal action of physostigma, and to examine the extent of this power and define its limits.

The former object has been effected by a detailed account in Section A of several experiments in which the fatal action of a dose of physostigma equal to or greater than the minimum-lethal was prevented by the physiological action of a non-lethal dose of atropia, as well as by a brief account in Section B, of a larger number of similar experiments, which, however, are also described with greater detail in the Tabular Summary. The total number of these experiments is one hundred and sixty one; and in each of them the animal used was killed many days afterwards, and when the effects of the two substances had completely disappeared, by a dose of physostigma less than or only equal to that from which it had previously recovered.

The examination of the extent of the counteracting influence of atropia upon the lethal action of physostigma, as well as the defining of the limits of this influence have been accomplished in the manner and with the results fully described in Section B. By means of the three series of experiments contained in this section, it has been ascertained what is the maximum dose of physostigma that can be counteracted successfully by atropia, what are the doses of atropia that can counteract any given dose of physostigma, and what relation-

ship exists between the doses with which this mutual counteration occurs and the length of the interval of time by which the administration of atropia precedes or follows that of physostigma.

In presence of the many obvious proofs to the contrary contained in this paper, I have considered it superfluous to enter into any discussion of the possibility of this counteraction being the result either of some chemical reaction between atropia and physostigma, or of an increased rapidity in the elimination of the one substance produced by the action of the other. The conditions of the experiments, and the symptoms that were observed, render it certain that atropia prevents the fatal effect of a lethal dose of physostigma by so influencing the functions of certain structures, as to prevent such modifications from being produced in them by physostigma as would result in death. The one substance counteracts the action of the other; and the result is a physiological antagonism so remarkable and decided, that the fatal effect even of three and a half times the minimum-lethal dose of physostigma may be prevented by atropia. The existence of such an antagonism encourages the hope that the power of directly counteracting disease is far from unattainable, and it supplies a strong incentive to efforts designed to determine the conditions of disease and the actions of remedies with an exactitude sufficient to show how the remedial action may be applied as a counteracting influence to the diseased condition.

Explanation of Tabular Summary, &c.—In the Tabular Summary of Experiments, with which this paper ends, I have included only those experiments that are mentioned in Section B, and have endeavoured to state the leading conditions and symptoms of each experiment in as brief a manner as possible. The time of occurrence of each symptom is computed from the moment when the administration of the last-mentioned substance was commenced. It is proper to explain, that in the column of effects on secretion and excretion, the phrase "slight increase of secretion of certain buccal glands" implies merely that such an increase was inferred from certain movements of the lips suggestive of it; and that the phrase in the same column "*with atropia* none" implies merely that there was no evidence of any obvious effect; but it does not imply that diminution of secretion or excretion did not occur—for in such experiments the occurrence of this effect could not without great difficulty be certainly established. It will be observed that the size of the pupils is always indicated by two measurements: the first mentioned being the size in a perpendicular direction, and the second that in a horizontal one.

I have not considered it necessary to mention the symptoms that were observed in the *b* experiments (where a lethal dose of physostigma alone was

administered to an animal that had previously recovered from the combined administration of atropia and physostigma); for the symptoms were always very much the same, and a sufficient account of them has already been given in Section A. The *a* and *b* portions of each experiment in which they occur were performed on the same animal.

According to the system of enumeration that has been followed, the number of the experiments contained in this paper appears to be 331. This number, however, does not adequately represent the labour involved in the research, for it includes 159 experiments that consist of two parts (*a* and *b*), and one that consists of three parts (*a*, *b* and *c*); and as each of these parts is in reality a separate experiment, the total number is 492.

All these experiments were performed in the Materia Medica Laboratory of the University of Edinburgh, and I cannot sufficiently express my gratitude to Sir Robert Christison for having placed his laboratory at my disposal.

[This Paper was received for publication on Friday, November 10th, 1871. Since that time, several additions have been made to it by the Author, the most important of which is the insertion of Diagram 7 and its accompanying description.—J. H. B. *March 4th*, 1872.]

TABULAR SUMMARY OF THE EXPERIMENTS CONTAINED IN SECTION B.

SERIES I.—DETERMINATION OF THE LIMITS OF ANTAGONISM WHEN ATROPIA IS ADMINISTERED FIVE MINUTES BEFORE PHYSOSTIGMA.

TABLE 1.—Experiments with half the Minimum-Lethal Dose of Physostigma (0·6 *gr. of Extract of Physostigma per Three Pounds Weight of Rabbit*).

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The measurements are in fiftieths of an inch).	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
58.	3 lbs.	5·3	5·3	0·6	Recovery.	*With atropia*, in 6 min., dilatation from $\frac{13}{60} \times \frac{12}{60}$ to $\frac{17}{60} \times \frac{17}{60}$. *After physostigma*, in 20 min., the dilatation had increased to $\frac{18}{60} \times \frac{18}{60}$, and it remained so for more than 2 hours.—On the following day, the size was $\frac{18}{60} \times \frac{18}{60}$; and on the 9th day, $\frac{14}{60} \times \frac{14}{60}$.	*With atropia*, in 4 min. 30 sec., acceleration from 41 to 55 per 10 sec. *After physostigma*, slight slowing occurred. In 1 hour, the rate per 10 sec. was 49; and in 1 hour 50 min., 53.—On the following day, it was 61; and on the 6th day, 42.	*With atropia*, none noted. *After physostigma*, the respirations continued to occur at about their original rapidity.	*With atropia*, none. *After physostigma*, none. Neither defæcation nor urination occurred, nor was the secretion of any buccal gland increased during the 2 hours of continuous observation.	*With atropia*, none. *After physostigma*, in 12 min., a little restlessness and excitement; and in 18 min., slight paralysis, which became rather more marked in 25 min., and then gradually lessened. No tremors occurred. Fibrillary twitches were present during the first 12 min. only, and in a very slight form.
59.	3 lbs. 2 oz.	6·43	6·16	0·62	Recovery	*With atropia*, in 2 min. 30 sec., dilatation from $\frac{13}{60} \times \frac{11}{60}$ to $\frac{18}{60} \times \frac{17}{60}$. *After physostigma*, in 8 min., the size was $\frac{16}{60} \times \frac{16}{60}$, and it continued so for 1 hour 30 min.—On the following day, the size was $\frac{18}{60} \times \frac{18}{60}$; on the 7th day, $\frac{15}{60} \times \frac{15}{60}$; on the 12th day, $\frac{14}{60} \times \frac{13}{60}$; and on the 13th day, $\frac{12}{60} \times \frac{12}{60}$.	*With atropia*, in 4 min., acceleration from 42 to 64 per 10 sec. *After physostigma*, slowing occurred, and in 1 hour 25 min., the rate per 10 sec. was 40.—On the following day, it was about 68; on the 6th day, 52; and on the 10th day, 41.	*With atropia*, none noted. *After physostigma*, the respirations continued to occur at about their original rate for at least 1 hour 30 min.	*With atropia*, none. *After physostigma*, in 1 min., urine was voided, and again in 4 min., along with several normal fæcal pellets. No increase occurred in the secretion of any buccal gland.	*With atropia*, none. *After physostigma*, in 5 min., restlessness; and in 25 min., slight paralysis, which had not increased perceptibly in 1 hour 30 min. No tremors occurred, and fibrillary twitches were present only during the first 50 min., and in a slight form.
60.	3 lbs. 3 oz.	6·58	6·2	0·63	Recovery.	*With atropia*, in 3 min., dilatation from $\frac{10}{60} \times \frac{9}{60}$ to $\frac{18}{60} \times \frac{18}{60}$. *After physostigma*, the above dilatation continued for more than 2 hours.—On the following day, the size was $\frac{16}{60} \times \frac{14}{60}$; and on the 3d day, $\frac{10}{60} \times \frac{10}{60}$.	*With atropia*, in 4 min. 30 sec., acceleration from 42 to 54 per 10 sec. *After physostigma*, the rate was maintained at about 54 per 10 sec. for 2 hours.—On the following day, it was 40 per 10 sec.	*With atropia*, none noted. *After physostigma*, slowing occurred from the original rate of 26 per 10 sec. to in 10 min. 16 per 10 sec.; and this rate was continued until 2 hours.	*With atropia*, none. *After physostigma*, none. Neither defæcation nor urination occurred, nor was the secretion of any buccal gland increased during the 2 hours of continuous observation.	*With atropia*, none. *After physostigma*, in 7 min., restlessness; in 12 min., slight weakness; and in 1 hour, distinct paralysis. Occasionally, feeble starts occurred, and only very faint fibrillary twitches were developed.

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
61.	3 lbs. 2½ oz.	0·62	0·3	0·63	Recovery.	*With atropia*, in 4 min., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{16}{50} \times \frac{15}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 41 to 50 per 10 sec.	*With atropia*, in 4 min. 50 sec., slowing from 19 to 12 per 10 sec.	*With atropia*, none.	*With atropia*, none.
						After physostigma, the above size was continued for 2 hours.—On the following day, the size was $\frac{16}{50} \times \frac{16}{50}$; on the 5th day, $\frac{18}{50} \times \frac{18}{50}$; on the 6th day, $\frac{17}{50} \times \frac{17}{50}$; and on the 12th day, $\frac{15}{50} \times \frac{15}{50}$	*After physostigma*, the rate per 10 sec. was in 15 min., 56; in 26 min., 48; in 1 hour 20 min., 40; and in 2 hours, 34.—On the following day, the rate per 10 sec. was 41.	*After physostigma*, the rate per 10 sec. was in 16 min., 11; in 35 min., 14; and in 1 hour, 11.	*After physostigma*, none. Neither defæcation nor urination occurred, nor was the secretion of any buccal gland increased during the 2 hours of continuous observation.	*After physostigma*, in 15 min., slight paralysis, which increased a little until 1 hour, and then gradually lessened. Occasionally slight starts occurred. Fibrillary twitches were very slightly developed, and they appeared only for 12 min. after the injection of physostigma.
62.	3 lbs. 2 oz.	0·8	0·5	0·62	Recovery.	*With atropia*, in 4 min., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{15}{50} \times \frac{15}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 39 to 44 per 10 sec.	*With atropia*, none.	*With atropia*, none.	*With atropia*, none.
						After physostigma, in 8 min., further dilatation to $\frac{16}{50} \times \frac{16}{50}$; afterwards contraction occurred, and the size was in 2 hours, $\frac{14}{50} \times \frac{14}{50}$.—On the following day, the size was $\frac{16}{50} \times \frac{16}{50}$; and on the 3d day, $\frac{13}{50} \times \frac{12}{50}$.	*After physostigma*, the rate per 10 sec. was in 20 min., 50; in 38 min., 40; in 1 hour, 33; and in 2 hours 20 min., 41.—On the following day it was 39.	*After physostigma*, acceleration, and then slowing was produced. The rate per 10 sec. in 2 hours 30 min. was 14.	*After physostigma*, none.	*After physostigma*, in 10 min., weakness; in 1 hour, distinct paralysis; and in 2 hours 30 min., only slight weakness. Occasionally slight starts occurred. Fibrillary twitches were present in the earlier portion of the experiment, but only in a slight form.
63.	3 lbs. 3 oz.	7·43	7·	0·63	Recovery.	*With atropia*, in 4 min., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{16}{50} \times \frac{16}{50}$.	*With atropia*, in 3 min. 30 sec., acceleration from 40 to 49 per 10 sec.	*With atropia*, none noted.	*With atropia*, none.	*With atropia*, none.
						After physostigma, further dilatation to $\frac{17}{50} \times \frac{17}{50}$, and this size was maintained for more than 2 hours 40 min.	*After physostigma*, in 30 min., slowing had occurred to 40 per 10 sec., and this rate was maintained for more than 2 hours.—On the following day, the rate per 10 sec. was 56.	*After physostigma*, the rate per 10 sec. was in 3 min., 15; in 7 min., 28; in 18 min., 25; in 30 min., 13; and in 2 hours 40 min., 11.	*After physostigma*, none.	*After physostigma*, in 4 min., restlessness and excitement; in 15 min., slight paralysis; in 50 min., decided paralysis; and in 2 hours 40 min., slight paralysis. No tremors or starts occurred. Fibrillary twitches were present only during the first 20 min.
64.	3 lbs. 5 oz.	8·8	8·	0·66	Recovery.	*With atropia*, in 3 min. 30 sec., dilatation from $\frac{11}{50} \times \frac{10}{50}$ to $\frac{18}{50} \times \frac{18}{50}$.	*With atropia*, in 4 min. acceleration from 43 to 51 per 10 sec.	*With atropia*, none noted. The original rate was 35 per 10 sec.	*With atropia*, none.	*With atropia*, in 4 min., restlessness.
						After physostigma, the pupils remained about $\frac{16}{50} \times \frac{16}{50}$ for more than 2 hours 30 min.—On the following day, the size was $\frac{15}{50} \times \frac{15}{50}$; on the 8th day, also $\frac{18}{50} \times \frac{18}{50}$; and on the 18th day, $\frac{13}{50} \times \frac{13}{50}$.	*After physostigma*, in 35 min., slowing had occurred to 42 per 10 sec., and this rate was maintained for more than 2 hours.—On the following day, the rate per 10 sec. was 35; and on the 4th day, 45.	*After physostigma*, the rate per 10 sec. was in 10 min., 23; in 15 min., 34; in 50 min. 20; and in 2 hours 40 min., 16.	*After physostigma*, in 14 min., a few normal fæcal pellets. No urination occurred, nor was the secretion of any buccal gland increased during the 2 hours and 40 min. of continuous observation.	*After physostigma*, the restlessness continued for several min. In 30 min. slight paralysis; and in 1 hour well marked paralysis, which had not perceptibly lessened in 2 hours 40 min. No tremors occurred, and fibrillary twitches were present only during the first 10 min., and in a very slight

Number of Experiment.	Weight of Rabbit.	Sulphate of Atropia (in Grains). Actual Dose.	Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
65.	3 lbs. 7 oz.	10·	8·8	0·68	Recovery.	*With atropia*, in 3 min., dilatation from $\frac{13}{50} \times \frac{12}{50}$ to $\frac{16}{50} \times \frac{16}{50}$. *After physostigma*, the pupils remained about $\frac{16}{50} \times \frac{16}{50}$ for at least 2 hours.—On the following day, the size was $\frac{18}{50} \times \frac{18}{50}$.	*With atropia*, none noted. *After physostigma*, in 2 min., acceleration occurred from the original rate of 41 to 60 per 10 sec. Afterwards slowing took place, and in 1 hour the rate per 10 sec. was 41. — On the following day, the rate per 10 sec. was 48.	*With atropia*, none. *After physostigma*, slowing from the original rate per 10 sec. of 25 occurred, but subsequently, the original rate was reassumed.	*With atropia*, in 4 min., several normal fæcal pellets were passed, and urine was voided. *After physostigma*, none.	*With atropia*, in 4 min., restlessness and some excitement. *After physostigma*, restlessness and slight excitement continued for several minutes. In 19 min., decided paralysis, which somewhat increased, and had not lessened perceptibly in 2 hours 22 min. No tremors occurred, nor were any fibrillary twitches seen.
66.	2 lbs. 15 oz.	8·98	9·	0·587	Recovery.	*With atropia*, in 3 min. 30 sec., dilatation from $\frac{10}{50} \times \frac{9}{50}$ to $\frac{16}{50} \times \frac{16}{50}$. *After physostigma*, the above dilatation remained for at least 1 hour.—On the 3d day, the size was $\frac{18}{50} \times \frac{18}{50}$; on the 6th day, $\frac{13}{50} \times \frac{13}{50}$; and on the 9th day, $\frac{11}{50} \times \frac{10}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 38 to 58 per 10 sec. *After physostigma*, the rate per 10 sec. was in 15 min., 59; and in 45 min., about 54. — On the 3d day, it was 46; on the 6th day, 38; and on the 9th day, 41.	*With atropia*, in 4 min., slowing from 18 to 12 per 10 sec. *After physostigma*, in 20 min., the rate per 10 sec. was 13.	*With atropia*, none. *After physostigma*, in 5 min., several normal fæcal pellets were passed.	*With atropia*, none noted. *After physostigma*, restless and excited movements took place for about 25 minutes. Only a little weakness was present in 1 hour, when the observations were interrupted.
67.	3 lbs.	9·5	9·5	0·6	Recovery.	*With atropia*, in 3 min., dilatation from $\frac{11}{50} \times \frac{10}{50}$ to $\frac{15}{50} \times \frac{16}{50}$. *After physostigma*, in 12 min., the size was $\frac{14}{50} \times \frac{14}{50}$, and it remained so for at least 3 hours 48 min.—On the following day, the size was $\frac{17}{50} \times \frac{17}{50}$; on the 6th day, $\frac{12}{50} \times \frac{11}{50}$; and on the 12th day, $\frac{10}{50} \times \frac{9}{50}$.	*With atropia*, in 4 min., acceleration from 45 to at least 65 per 10 sec. *After physostigma*, in 12 min., the rate per 10 sec. was about 68; in 20 min., 56; in 30 min., 42; in 1 hour 10 min., 38; and in 1 hour 35 min., 33. The impulse was very strong at first, but in 20 min. it was weak, and after 1 hour 20 min. so weak that it could not accurately be counted. — On the following day, the impulse was strong, and the rate per 10 sec., 52; and on the 4th day, the rate per 10 sec. was 41.	*With atropia*, none. *After physostigma*, slowing occurred from the original rate per 10 sec. of 25. In 10 min. it was 15; in 30 min., 13; and in 3 hours, 10. In 2 hours 25 min. the respirations were extremely weak and shallow, and they continued so until after 3 hours 40 min.	*With atropia*, none. *After physostigma*, none. Neither defæcation nor urination occurred, nor was the secretion of any buccal gland increased during the 3 hours and 40 min. of continuous observation.	*With atropia*, restlessness, and occasionally slight starts with the respirations. *After physostigma*, restlessness continued during a few minutes. In 9 min., weakness; in 13 min., distinct though slight paralysis; and in 2 hours, well-marked paralysis and flaccidity, which were still present at 3 hours 40 min. Weak tremors and general spasms occasionally took place. Fibrillary twitches were present only during the first 20 min., and in a very slight form.

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal	Dose of Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
68.	3 lbs.	9·8	9·8	0·6	Death, in 1 hour 15 min. after the administration of physostigma.	*With atropia*, in 3 min., dilatation from $\frac{11}{50} \times \frac{10}{50}$ to $\frac{15}{50} \times \frac{15}{50}$. *After physostigma*, the size remained about $\frac{15}{50} \times \frac{15}{50}$ until death. — After death the size was in 6 min., $\frac{15}{50} \times \frac{14}{50}$; in 25 min., $\frac{14}{50} \times \frac{14}{50}$; in 1 hour, $\frac{14}{50} \times \frac{14}{50}$; and in 1 hour 20 min., $\frac{15}{50} \times \frac{15}{50}$.	*With atropia*, in 3 min. 30 sec., acceleration from 41 to 59 per 10 sec. *After physostigma*, in 15 min., the rate per 10 sec. was about 60; and in 38 min., about 42. The impulse became so weak in 35 min. that it was difficult to count the rate accurately.	*With atropia*, none noted. *After physostigma*, the rate per 10 sec. was in 6 min., 14; in 1 hour, 8; in 1 hour 5 min., 5; and afterwards irregular and feeble gasps occurred until death.	*With atropia*, none. *After physostigma*, none. Neither defæcation nor urination occurred, nor was the secretion of any gland increased.	*With atropia*, none. *After physostigma*, in 20 min., slight paralysis, and in 1 hour general flaccidity, which increased until death. Occasionally tremors and general spasms occurred. Fibrillary twitches were present during only the first 15 min.; a slight degree of stiffness was present in the limbs 25 min. after death (temp. of laboratory, 56° F.)
69.	3 lbs.	10·	10·	0·6	Death, in 2 hours 27 min. after the administration of physostigma.	*With atropia*, in 3 min., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{16}{50} \times \frac{16}{50}$. *After physostigma*, the above dilatation was continued until death. —After death the size was in 3 min., $\frac{15}{50} \times \frac{15}{50}$; and in 15 min., $\frac{15}{50} \times \frac{15}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 44 to 52 per 10 sec. *After physostigma*, the rate per 10 sec. was in 15 min., 41; in 37 min., 39; and in 1 hour 40 min., 35. The impulse became weak in about 14 min.	*With atropia*, none noted. *After physostigma*, the rate per 10 sec. was in 12 min., 20; in 1 hour 35 min. 15; in 1 hour 50 min., 7; and soon afterwards the respirations became gasping.	*With atropia*, none. *After physostigma*, none, except that in 1 hour 50 min. a few drops of urine escaped during some spasms.	*With atropia*, none. *After physostigma*, in 37 min., decided paralysis; and in 1 hour 50 min., general flaccidity which continued until death. Occasionally tremors and general spasms occurred. No fibrillary twitches were seen.
70.	3 lbs. 2 oz.	10·9	10·5	0·63	Death, in 42 min. after the administration of physostigma.	*With atropia*, in 4 min., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{16}{50} \times \frac{15}{50}$. *After physostigma*, the size was in 4 min., $\frac{17}{50} \times \frac{16}{50}$; and in 38 min., $\frac{18}{50} \times \frac{18}{50}$.—After death, in 4 min., $\frac{12}{50} \times \frac{12}{50}$; and in 15 min., $\frac{9}{50} \times \frac{9}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 37 to 49 per 10 sec. *After physostigma*, the rate per 10 sec. was in 3 min., 52; and in 30 min., about 49.	*With atropia*, in 4 min. 15 sec., slowing from 18 to 16 per 10 sec. *After physostigma*, the rate per 10 sec. was in 3 min., 17; in 12 min., 14; in 22 min., 9; and in 34 min., 4. Afterwards weak and irregular gasps occurred until death.	*With atropia*, none. *After physostigma*, in 6 min., a little urine was voided. No defæcation occurred, nor was the secretion of any buccal gland increased.	*With atropia*, none. *After physostigma*, restlessness and excitement were present for a few minutes. In 8 min., slight paralysis; and in 28 min., general flaccidity, which continued until death. A few tremors and feeble spasms occurred. Fibrillary twitches were present only during the earlier part of the experiment, and in an extremely slight form.

WITH THE MINIMUM-LETHAL DOSE OF PHYSOSTIGMA (1·2 *gr. of Extract of Physostigma per Three Pounds Weight of Rabbit.*)

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
71.	3 lbs.	0·005	0·005	1·2	Death, in 31 min. after the administration of physostigma.	*With atropia*, none. The original size was $\frac{10}{50} \times \frac{9}{50}$. *After physostigma*, the size was in 5 min., $\frac{12}{50} \times \frac{11}{50}$; in 11 min., $\frac{10}{50} \times \frac{9}{50}$; in 14 min., $\frac{7}{50} \times \frac{6}{50}$; in 19 min., $\frac{4}{50} \times \frac{3}{50}$; and in 30 min., $\frac{4}{50} \times \frac{3}{50}$. — After death, it was in 20 min., $\frac{7}{50} \times \frac{6}{50}$; and in 34 min., $\frac{10}{50} \times \frac{9}{50}$.	*With atropia*, none. The original rate was 44 per 10 sec. *After physostigma*, only decrease in the rate was observed.	*With atropia*, none. The original rate was 34 per 10 sec. *After physostigma*, the rate per 10 sec. was in 21 min., 21; and in 29 min., 13. Afterwards the respirations became gasping and very irregular.	*With atropia*, none. *After physostigma*, in 10 min., several normal fæcal pellets were passed; in 15 min., slight salivation, which afterwards became increased; and in about 15 min., increase of buccal, laryngeal and bronchial secretions, causing noisy respiration.	*With atropia*, none. *After physostigma*, in 1 min. 30 sec., infrequent fibrillary twitches, which soon became pretty well marked. In 6 min., slight feebleness; in 10 min., distinct paralysis; and in 21 min., general flaccidity. Occasionally, feeble tremors and spasms occurred.—After death, the first appearance of rigor was at about 34 min. (temp. of laboratory, 55° F.)
72. *a*	2 lbs. 15 oz. [Experiment *b* was performed nine days after experiment *a*.]	0·01	0·009	1·175	Recovery.	*With atropia*, in 4 min. 30 sec., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{13}{50} \times \frac{13}{50}$. *After physostigma* the size was in 9 min., $\frac{16}{50} \times \frac{15}{50}$; and in 24 min., $\frac{14}{50} \times \frac{14}{50}$.—On the following day it was $\frac{11}{50} \times \frac{10}{50}$.	*With atropia*, in 4 min. 35 sec., acceleration from 38 to 40 per 10 sec. *After physostigma*, no observations were made until 1 hour 15 min., when the rate was 43 per 10 sec.—On the following day it was 40.	*With atropia*, none. The original rate was 21 per 10 sec. *After physostigma*, slight acceleration followed by slowing.	*With atropia*, none. *After physostigma*, in 24 min., pultaceous fæces were passed, and afterwards fæces of semi-liquid consistence; and in 42 min., urine was voided. In 16 min., salivation; and afterwards increase of laryngeal and bronchial secretions, causing noisy respiration, which continued for more than 1 hour 10 min.	*With atropia*, none. *After physostigma*, in 2 min., infrequent fibrillary twitches, which soon became well-marked. In 8 min., slight paralysis; in 40 min., very decided paralysis; and in 1 hour 30 min., almost no paralysis.
b	2 lbs. 15 oz.	0	0	1·17 (= 1·2 gr. p. 3 lbs.)	Death, in 29 min.	—	—	—	—	—
73. *a*	3 lbs. [Experiment *b* was performed eight days after experiment *a*.]	0·015	0·015	1·2	Recovery.	*With atropia*, none. *After physostigma*, in 17 min., considerable dilatation, which had disappeared by the following day.	*With atropia*, in 4 min., acceleration from 41 to 46 per 10 sec. *After physostigma*, the above increased rate had returned to the normal rate in 2 hours.	*With atropia*, none. *After physostigma*, in 20 min., slowing from 33 to 21 per 10 sec.	*With atropia*, none. *After physostigma*, in 2 hours, several normal fæcal pellets were passed. No other effect on secretion or excretion occurred.	*With atropia*, none. *After physostigma*, fibrillary twitches became very well marked and continued to end of experiment. In 10 min., decided general paralysis, which had disappeared in 2 hours 10 min. A few tremors occurred at 15 min.
b	3 lbs.	0	0	1·2	Death, in 13 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
74. *a* [Experiment *b* was performed nine days after experiment *a*.]	3 lbs. 1 oz.	0·02	0·02	1·25	Recovery.	*With atropia*, in 4 min., dilatation from $\frac{1}{50} \times \frac{1}{50}$ to $\frac{14}{50} \times \frac{14}{50}$. *After physostigma*, in 8 min., further dilatation to $\frac{18}{50} \times \frac{18}{50}$; afterwards, contraction in 19 min., to $\frac{15}{50} \times \frac{15}{50}$; and in 32 min., to $\frac{11}{50} \times \frac{10}{50}$.	*With atropia*, in 4 min. 10 sec., acceleration from 39 to 41 per 10 sec. *After physostigma*, no observation was possible on account of the fibrillary twitches.—On the second day, the rate was 41 per 10 sec.	*With atropia*, none. *After physostigma*, at first, acceleration, and afterwards slowing.	*With atropia*, none. *After physostigma*, in 30 min., salivation and increase of the bronchial and buccal secretions, which became very excessive, and, though diminished, had not disappeared in 1 hour.	*With atropia*, none. *After physostigma*, fibrillary twitches became very well marked. In 15 min., decided general paralysis, which had nearly disappeared in 1 hour 10 min.
	b 3 lbs. 1 oz.	0	0	1·2	Death, in 34 min.	—	—	—	—	—
75. *a* [Experiment *b* was performed ten days after experiment *a*.]	3 lbs.	0·025	0·025	1·2	Recovery.	*With atropia*, in 4 min. 20 sec., dilatation from $\frac{11}{50} \times \frac{10}{50}$ to $\frac{14}{50} \times \frac{14}{50}$. *After physostigma*, in 6 min., further dilatation to $\frac{16}{50} \times \frac{16}{50}$; and in 1 hour, contraction to $\frac{12}{50} \times \frac{11}{50}$.	*With atropia*, in 4 min., acceleration from 38 to 49 per 10 sec. *After physostigma*, in 18 min., the rate was reduced to 46 per 10 sec.; in 24 min., to 29; and in 52 min., to 27.	*With atropia*, none noted. *After physostigma*, considerable slowing.	*With atropia*, none. *After physostigma*, in 28 min., normal fæces and urine; in 1 hour 18 min., slightly pultaceous fæces, and, also, in 2 hours 15 min. No salivation, and no increase of buccal or laryngeal secretions occurred.	*With atropia*, none. *After physostigma*, fibrillary twitches soon occurred, and continued for more than 2 hours 20 min. In 10 min., slight paralysis; in 15 min., decided paralysis; and in 1 hour, only slight weakness.
	b 3 lbs. 3 oz.	0	0	1·2	Death, in 29 min.	—	—	—	—	—
76. *a* [Experiment *b* was performed eight days after experiment *a*.]	3 lbs. 1 oz.	0·0312	0·031	1·25	Recovery.	*With atropia*, in 3 min., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{15}{50} \times \frac{14}{50}$. *After physostigma*, in 2 min., further dilatation to $\frac{15}{50} \times \frac{15}{50}$; then contraction, in 15 min. to $\frac{14}{50} \times \frac{13}{50}$; and in 28 min., to $\frac{12}{50} \times \frac{11}{50}$.	*With atropia*, in 4 min., acceleration from 41 to 50 per 10 sec. *After physostigma*, no observation was possible on account of the excessive fibrillary twitches.—On the following day, the rate was 45 per 10 sec.	*With atropia*, none noted. *After physostigma*, slowing, until in 1 hour the rate was 14 per 10 sec., the original rate having been 20 per 10 sec.	*With atropia*, none. *After physostigma*, in 13 min., soft fæces were passed; in 32 min., increase of laryngeal and bronchial secretions; and in 40 min., salivation.	*With atropia*, none. *After physostigma*, in 9 min., weakness; and in 17 min., decided paralysis. The paralysis had disappeared by 1 hour 40 min. Fibrillary twitches continued for more than 2 hours.
	b 3 lbs. 2 oz.	0	0	1·25 (= 1·2 gr. p. 3 lbs.)	Death, in 27 min.	—	—	—	—	—
77. *a* [Experiment *b* was performed ten days after experiment *a*.]	2 lbs. 15½ oz.	0·049	0·05	1·19	Recovery.	*With atropia*, in 4 min., dilatation from $\frac{12}{50} \times \frac{12}{50}$ to $\frac{15}{50} \times \frac{15}{50}$. *After physostigma*, the pupils continued during the experiment, $\frac{15}{50} \times \frac{15}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 40 to 45 per 10 sec. *After physostigma*, the rate was maintained at about 45 per 10 sec. as far as could be ascertained.	*With atropia*, in 3 min., acceleration from 14 to 19 per 10 sec. *After physostigma*, unimportant slowing occurred.	*With atropia*, none. *After physostigma*, in 24 min., pultaceous fæces; in 40 min., semi-liquid fæces and gelatinous matter; and in 1 hour and 40 min., pultaceous fæces and a little urine were passed. Neither salivation nor increase of the bronchial, &c., secretions occurred.	*With atropia*, none. *After physostigma*, in 8 min., weakness; and in 10 min., obvious paralysis and tremors: both of which had disappeared at 1 hour 30 min. Fibrillary twitches continued from the injection until after 2 hours.
	b 3 lbs.	0	0	1·2	Death, in 20 min. 30 sec.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose.	Dose of Physostigma (in Grains). Dose p. 3 lbs. of Animal.	Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
41.* *a* [Experiment *b* was performed ten days after experiment *a*.]	2 lbs. 15½ oz.	0·3	0·3	1·2	Recovery.	*With atropia*, in 2 min. 30 sec., dilatation from $\frac{14}{50}\times\frac{13}{50}$ to $\frac{18}{50}\times\frac{18}{50}$. *After physostigma*, the size was in 9 min., $\frac{8}{50}\times\frac{18}{50}$; and in 1 hour 30 sec., $\frac{16}{50}\times\frac{16}{50}$.—On the following day, the size was $\frac{16}{50}\times\frac{16}{50}$; and on the 5th day, $\frac{14}{50}\times\frac{13}{50}$.	*With atropia*, in 4 min., acceleration from 40 to 54 per 10 sec. *After physostigma*, the rate per 10 sec. was in 14 min., about 46; and in 1 hour 30 min., 40.—On the following day it was 52; and on the 5th day, 41.	*With atropia*, none noted. The original rate was 12 per 10 sec. *After physostigma*, the rate per 10 sec. was in 57 min., 16.—On the following day it was 12.	*With atropia*, none. *After physostigma*, in 1 hour 3 min. and in 1 hour 16 min., pultaceous fæces were passed; in 1 hour, urine was voided; and in 1 hour 16 min., the secretion of certain buccal glands was increased.	*With atropia*, none. *After physostigma*, in 2 min., slight fibrillary twitches, which soon became well marked. In 10 min., weakness; in 26 min., decided paralysis; and in 57 min., almost no paralysis. Occasionally weak tremors and starts occurred.
b	3 lbs.	0	0	1·2	Death, in 27 min.	—	—	—	—	—
78. *a* [Experiment *b* was performed eleven days after experiment *a*.]	3 lbs. 4 oz.	1·	0·92	1·3	Recovery.	*With atropia*, in 4 min., dilatation from $\frac{12}{50}\times\frac{11}{50}$ to $\frac{16}{50}\times\frac{15}{50}$. *After physostigma*, the pupils became fully dilated, and even on the 7th day the size was $\frac{16}{50}\times\frac{16}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 42 to 58 in 10 sec. *After physostigma*, the acceleration was somewhat increased, and then the rate remained at about 58 per 10 sec.—On the 3d day the rate was 45 per 10 sec.	*With atropia*, inconsiderable acceleration. *After physostigma*, a slightly accelerated rate was maintained.	*With atropia*, none. *After physostigma*, none.	*With atropia*, none. *After physostigma*, in 9 min., weakness, which became a little increased in 20 min., but no marked paralysis was at any time present. Fibrillary twitches were never excessive, and they were only slight during the greater part of the experiment.
b	3 lbs. 4 oz.	0	0	1·3 (= 1·2 gr. p. 3 lbs.)	Death, in 25 min.	—	—	—	—	—
79. *a* [Experiment *b* was performed ten days after experiment *a*.]	3 lbs. 3 oz.	2·1	2·	1·27	Recovery.	*With atropia*, in 3 min., dilatation from $\frac{12}{50}\times\frac{11}{50}$ to $\frac{15}{50}\times\frac{15}{50}$. *After physostigma*, in 2 min., further dilatation to $\frac{16}{50}\times\frac{16}{50}$, and this was maintained for more than 1 hour 30 min.	*With atropia*, in 4 min., acceleration from 41 to 51 per 10 sec. *After physostigma*, in a few minutes, further acceleration, and then gradual slowing until, in 50 min., the rate was 40 per 10 sec.—On the following day the rate was 36 per 10 sec.	*With atropia*, none observed. *After physostigma*, a slight slowing occurred.	*With atropia*, none. *After physostigma*, in 11 min., normal fæcal pellets were passed, and in 50 min., some more normal pellets. In 55 min., urination. There was neither salivation nor increase of the buccal, bronchial, or other secretions.	*With atropia*, none. *After physostigma*, in 17 min., fibrillary twitches were well marked and universal. In 40 min., decided weakness was present, but it soon disappeared, and no marked symptoms of paralysis were observed.
b	3 lbs.	0	0	1·2	Death, in 23 min.	—	—	—	—	—
80. *a* [Experiment *b* was performed eight days after experiment *a*.]	3 lbs.	3·	3·	1·2	Recovery.	*With atropia*, in 3 min., dilatation from $\frac{13}{50}\times\frac{12}{50}$ to $\frac{16}{50}\times\frac{16}{50}$. *After physostigma*, in 4 min., further dilatation to $\frac{18}{50}\times\frac{18}{50}$, and this was maintained for more than 2 days.	*With atropia*, in 4 min., acceleration from 42 to 60 per 10 sec. *After physostigma*, in 30 min., slowing to 52 per 10 sec., and in 1 hour 10 min., to 45 per 10 sec.—On the following day, the rate was 35 per 10 sec.	*With atropia*, acceleration. *After physostigma*, the respirations were maintained at about 17 per 10 sec.	*With atropia*, none. *After physostigma*, none.	*With atropia*, none. *After physostigma*, fibrillary twitches occurred during the whole experiment. In 22 min., slight paralysis; in 32 min., more decided, though only slight, paralysis. There was no evidence of paralysis in 1 hour 30 min.
b	3 lbs. ½ oz.	0	0	1·2	Death, in 19 min. 20 sec.	—	—	—	—	—

* A full description of this experiment has already been given in Section A (see p. 544).

Number of Experiment.		Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
81.	*a* [Experiment *b* was performed eleven days after experiment *a*.]	3 lbs.	4·3	4·3	1·2	Recovery.	*With atropia*, in 3 min., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{15}{50} \times \frac{16}{50}$. *After physostigma*, in 3 min., further dilatation to $\frac{16}{50} \times \frac{16}{50}$; and in 1 hour, or less, to $\frac{17}{50} \times \frac{17}{50}$. —On the following day the size was $\frac{18}{50} \times \frac{18}{50}$; on the 6th day, $\frac{16}{50} \times \frac{15}{50}$; and on the 8th day, $\frac{12}{50} \times \frac{12}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 44 to 53 per 10 sec. *After physostigma*, in 40 min., slowing to 42 per 10 sec., which rate was present in 1 hour. —On the following day the rate was 41 per 10 sec.	*With atropia*, in 4 min., acceleration from 20 to 23 per 10 sec. *After physostigma*, an accelerated rate was maintained until 1 hour 4 min., when the rate was 17 per 10 sec.	*With atropia*, none. *After physostigma*, none.	*With atropia*, none. *After physostigma*, only very slight fibrillary twitches until 1 hour 6 min., when they became more marked. In 22 min., distinct, though slight general paralysis; but in 1 hour even this had been recovered from.
	b	3 lbs.	0	0	1·2	Death, in 38 min.	—	—	—	—	—
82.	*a* [Experiment *b* was performed nine days after experiment *a*.]	3 lbs.	5·	5·	1·2	Recovery.	*With atropia*, in 4 min., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{15}{50} \times \frac{15}{50}$. *After physostigma*, in 40 min., or less, contraction to $\frac{15}{50} \times \frac{15}{50}$.—On the following day, $\frac{16}{50} \times \frac{15}{50}$ ×; and on the 7th day, $\frac{13}{50} \times \frac{12}{50}$.	*With atropia*, in 4 min. 20 sec., acceleration from 38 to 52 per 10 sec. *After physostigma*, in 40 min., slowing to 49 per 10 sec.; and in 2 hours 25 min., to 38 per 10 sec.—On the following day, the rate was 38 per 10 sec.; on the 6th day, 48; and on the 8th day, 41.	*With atropia*, none noted. *After physostigma*, the rate was maintained nearly the same as before the experiment.	*With atropia*, none. *After physostigma*, normal fæcal pellets were several times passed, and urination occurred in 2 hours 30 min. There was neither salivation nor increase in the bronchial, &c., secretions.	*With atropia*, none. *After physostigma*, only very slight fibrillary twitches occurred, and only slight paralytic symptoms; the latter were most marked in about 20 min.
	b	2 lbs. 15 oz.	0	0	1·2	Death, in 29 min.	—	—	—	—	—
83.	*a* [Experiment *b* was performed eleven days after Experiment *a*.]	3 lbs.	5·2	5·2	1·2	Recovery.	*With atropia*, in 3 min., dilatation from $\frac{11}{50} \times \frac{10}{50}$ to $\frac{14}{50} \times \frac{14}{50}$. *After physostigma*, in 2 min., further dilatation to $\frac{16}{50} \times \frac{16}{50}$, and this size maintained. — On the following day, the size was $\frac{15}{50} \times \frac{14}{50}$; and on the 8th day, $\frac{13}{50} \times \frac{12}{50}$.	*With atropia*, in 4 min., acceleration from 39 to 48 per 10 sec. *After physostigma*, no observations until the following day, when the rate was 39 per 10 sec. —On the 4th day the rate was 40 per 10 sec.	*With atropia*, none. *After physostigma*, in 32 min., slowing from original rate of 22 to 14 per 10 sec.—On the following day the rate was 12 per 10 sec.; and on the 3d day, 19 per 10 sec.	*With atropia*, none. *After physostigma*, none. No salivation, defæcation, urination, &c., during the 1 hour and 30 min. of continuous observation.	*With atropia*, none. *After physostigma*, in 15 min., slight paralysis; in 32 min., decided paralysis; and in 37 min., paralysis, along with spasmodic movements, which continued for about 30 min., after which the spasms disappeared, and the paralysis abated. Only slight fibrillary twitches occurred, but none were present after the first 40 min.
	b	3 lbs.	0	0	1·2	Death, in 21 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Dose of Extract (in Grains). Actual Dose.	Dose of Extract (in Grains). Dose p. 3 lbs. of Animal.	Quantity of Extract (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
84.	3 lbs.	5·3	5·3	1·2	Death, in 59 min. after the administration of physostigma.	*With atropia*, in 3 min., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{15}{50} \times \frac{15}{50}$. *After physostigma*, in 2 min., further dilatation to $\frac{16}{50} \times \frac{16}{50}$, which continued until death.—In 2 min. after death, the size was $\frac{14}{50} \times \frac{14}{50}$; and in 16 min., $\frac{8}{50} \times \frac{7}{50}$.	*With atropia*, in 4 min., acceleration from 42 to 51 per 10 sec. *After physostigma*, no observations were made because of the serious character of the general symptoms.	*With atropia*, in 3 min. 30 sec., slowing from 21 to 19 per 10 sec. *After physostigma*, further slowing in 21 min. to 13; in 42 min. to 12; and in 45 min. to 11. Their character was now feeble and shallow, and they gradually became more so, until death.	*With atropia*, none. *After physostigma*, none. No salivation, defæcation, nor urination at any time.	*With atropia*, none. *After physostigma*, in 10 min., slight paralysis; in 13 min., decided paralysis; and in 43 min., flaccidity, accompanied with weak spasms and tremors, and which continued until death. There were only slight fibrillary twitches, which occurred soon after the injection of physostigma.
85.	2 lbs. 15½ oz.	5·28	5·3	1·18	Death, in 1 hour 11 min. after the administration of physostigma.	*With atropia*, in 3 min., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{15}{50} \times \frac{15}{50}$. *After physostigma*, in 3 min., further dilatation to $\frac{16}{50} \times \frac{16}{50}$; in 1 hour 3 min., contraction to $\frac{15}{50} \times \frac{15}{50}$, which remained till death.—After death, in 5 min., $\frac{14}{50} \times \frac{14}{50}$; in 10 min., $\frac{13}{50} \times \frac{13}{50}$; and in 16 min., $\frac{12}{50} \times \frac{12}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 41 to 53 per 10 sec. *After physostigma*, in 22 min., slowing to 48 per 10 sec.; in 29 min., to 40; and in 35 min., to 38. Further changes were not observed.	*With atropia*, none. *After physostigma*, the original rate of 16 per 10 sec. was present at 22 min.; slowing then occurred, and in 1 hour 5 min., only gasps occurred 3 times in 10 sec.	*With atropia*, none. *After physostigma*, none. No salivation, defæcation, nor urination at any time.	*With atropia*, none. *After physostigma*, in 12 min., slight paralysis; in 30 min., decided paralysis; and in 54 min., general flaccidity. No spasms occurred, and but slight fibrillary twitches at only the earlier part of the experiment.
86.	3 lbs.	5·4	5·4	1·2	Death, in 50 min. after the administration of physostigma.	*With atropia*, in 3 min., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{15}{50} \times \frac{15}{50}$. *After physostigma*, in 3 min., further dilatation to $\frac{17}{50} \times \frac{17}{50}$; this size was maintained until 18 min.; but in 32 min., $\frac{15}{50} \times \frac{15}{50}$, and this size was maintained until death.—After death, in 1 min., $\frac{13}{50} \times \frac{13}{50}$; in 3 min., $\frac{11}{50} \times \frac{10}{50}$; in 5 min., $\frac{9}{50} \times \frac{8}{50}$; and in 20 min., $\frac{5}{50} \times \frac{4}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 39 to 49 per 10 sec. *After physostigma*, no observation was made until 27 min., when the rate was 45 per 10 sec.	*With atropia*, none. *After physostigma*, slowing occurred from the original rate per 10 sec. of 19; in 10 min., to 16; in 20 min., to 13; in 37 min., to 11; in 42 min., to 8; and in 49 min., to 2 feeble gasps per 10 sec.	*With atropia*, none. *After physostigma*, none. No salivation, defæcation, nor urination at any time.	*With atropia*, none. *After physostigma*, in 8 min., slight paralysis; in 13 min., decided paralysis, and occasionally tremors; in 36 min., spasms; and in 40 min., general flaccidity. Only soon after the injection of physostigma, slight fibrillary twitches occurred.
87.	3 lbs.	5·5	5·5	1·2	Death, in 1 hour 25 min. after the administration of physostigma.	*With atropia*, in 3 min. 30 sec., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{18}{50} \times \frac{18}{50}$. *After physostigma*, in 20 min., further dilatation to $\frac{17}{50} \times \frac{17}{50}$, and in 1 hour 17 min. to $\frac{18}{50} \times \frac{18}{50}$.—After death, in 45 min., contraction to $\frac{16}{50} \times \frac{16}{50}$ had occurred.	*With atropia*, in 4 min., acceleration from 39 to 52 per 10 sec. *After physostigma*, in 30 min., slowing to 41; and in 58 min., to 31 per 10 sec. Further observations were not made, as the contact of the hand excited tremors, and greatly distressed the rabbit.	*With atropia*, in 4 min. 20 sec., slowing from 19 to 17 per 10 sec. *After physostigma*, in 18 min., acceleration to 33; in 54 min., slowing to 15; and in 1 hour 19 min., to 6 per 10 sec.	*With atropia*, none. *After physostigma*, in 3 min., several normal fæcal pellets were passed; otherwise, no effect.	*With atropia*, none. *After physostigma*, in 18 min., decided paralysis was present; in 30 min., flaccidity and weak spasms; in 1 hour, great flaccidity, accompanied with spasms; and in 1 hour and 24 min. weak tremors occurred. Slight fibrillary twitches occurred, only shortly after the injection of physostigma.

TABLE 3.—EXPERIMENTS WITH ONE-AND-A-HALF TIMES THE MINIMUM-LETHAL DOSE OF PHYSOSTIGMA (1·8 *gr. of Extract of Physostigma per Three Pounds Weight of Rabbit.*)

Number of Experiment.	Weight of Rabbit	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal	Dose of Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
88.	3 lbs. 2 oz.	0·015	0·014	0·187	Death, in 23 min. after the administration of physostigma.	*With atropia*, in 4 min., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{16}{50} \times \frac{16}{50}$. *After physostigma*, in 3 min., further dilatation to $\frac{16}{50} \times \frac{16}{50}$; subsequently contraction.	*With atropia*, in 4 min. 20 sec., acceleration from 34 to 44 per 10 sec. *After physostigma*, in 16 min., slowing to 37 per 10 sec. No further observations were made.	*With atropia*, in 4 min. 30 sec., slowing from 22 to 18 per 10 sec. *After physostigma*, in 4 min., acceleration to 19; and in 18 min., slowing to 16 per 10 sec. The slowing continued until death.	*With atropia*, none. *After physostigma*, in 14 min., increase of bronchial, laryngeal, and salivary secretions. This increase became greater as death approached.	*With atropia*, none. *After physostigma*, fibrillary twitches, which soon became very well marked. In 7 min., slight paralysis; in 10 min., decided paralysis and tremors; and in 15 min., flaccidity, accompained with tremors and weak spasms.
89.	3 lbs. 1 oz.	0·015	0·015	0·18	Death, in 32 min. after the administration of physostigma.	*With atropia*, none. *After physostigma*, in 3 min., further dilatation to $\frac{16}{50} \times \frac{16}{50}$; in 20 min., contraction to $\frac{12}{50} \times \frac{11}{50}$; in 25 min., to $\frac{9}{50} \times \frac{8}{50}$; in 28 min., to $\frac{7}{50} \times \frac{6}{50}$; and in 30 min., to $\frac{4}{50} \times \frac{5}{50}$.—At death, the size was $\frac{7}{50} \times \frac{6}{50}$; in 3 min. afterwards, $\frac{4}{50} \times \frac{3}{50}$; and in 8 min., $\frac{10}{50} \times \frac{10}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 45 to 48 per 10 sec. *After physostigma*, in 19 min., slowing to 32 per 10 sec., and the slowing increased until death.	*With atropia*, none. *After physostigma*, slowing, then acceleration, and then slowing occurred. In 28 min., only 9 laboured and noisy gasps occurred per 10 sec.; and in 30 min., about 2 per 10 sec.	*With atropia*, none. *After physostigma*, in 17 min., slight salivation, which increased gradually; and in 28 min., several wet fæcal pellets were passed.	*With atropia*, none. *After physostigma*, fibrillary twitches, which soon became very well marked. In 8 min., weakness; and in 10 min., decided paralysis, which quickly increased. Tremors and weak starts frequently occurred.
90. *a* [Experiment *b* was performed eleven days after experiment *a*.]	3 lbs. 1 oz.	0·02	0·02	1·83	Recovery.	*With atropia*, none noted. *After physostigma*, none noted.	*With atropia*, in 4 min. 30 sec., acceleration from 38 to 42 per 10 sec. *After physostigma*, considerable slowing occurred.	*With atropia*, in 3 min., slowing from 21 to 17 per 10 sec. *After physostigma*, none noted.	*With atropia*, none. *After physostigma*, urine was voided, and a few normal fæcal pellets passed; and considerable salivation occurred.	*With atropia*, none. *After physostigma*, in 16 min., decided paralysis, which continued for more than 40 min. Fibrillary twitches were very well marked.
b	3 lbs. 5 oz.	0	0	1·3 (= 1·2 gr. p. 3 lbs.)	Death, in 24 min.	—	—	—	—	—
91.	3 lbs.	0·02	0·02	1·8	Death, in more than 2 hours after the administration of physostigma.*	*With atropia*, in 4 min. 30 sec., dilatation from $\frac{16}{50} \times \frac{14}{50}$ to $\frac{16}{50} \times \frac{15}{50}$. *After physostigma*, in 8 min., further dilatation to $\frac{17}{50} \times \frac{17}{50}$; and in 14 min., to $\frac{18}{50} \times \frac{18}{50}$. Afterwards, contraction, which in 1 hour 35 min. had reached $\frac{18}{50} \times \frac{12}{12}$	*With atropia*, in 4 min., acceleration from 42 to 48 per 10 sec. *After physostigma*, slowing occurred; and in 35 min. the rate per 10 sec. was 45, while in 1 hour 50 min. it was 26.	*With atropia*, in 4 min. 20 sec., slowing from 35 to 31 per 10 sec. *After physostigma*, slowing occurred; and in 35 min. the rate per 10 sec. was 22; while in 1 hour and 26 min., it was 9.	*With atropia*, none. *After physostigma*, in 17 min., several normal fæcal pellets; soon afterwards salivation occurred, and continued along with the increased secretion of other buccal glands until after 1 hour and 50 min.	*With atropia*, none. *After physostigma*, in 8 min., distinct paralysis; and in 13 min., well marked paralysis, which continued along with gentle tremors for more than 2 hours. Fibrillary twitches were present during all this time in an exaggerated form.

Number of Experiment.	Weight of Rabbit.	Sulphate of Atropia (in Grains). Actual Dose.	Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
92. *a* [Experiment *b* was performed ten days after experiment *a*.]	3 lbs.	0·02	0·02	1·8	Recovery.	*With atropia*, in 4 min., dilatation from $\frac{10}{50} \times \frac{9}{50}$ to $\frac{11}{50} \times \frac{10}{50}$. *After physostigma*, further dilatation, until in 12 min. the size was $\frac{15}{50} \times \frac{15}{50}$; then contraction, until in 43 min., the size was $\frac{13}{50} \times \frac{13}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 40 to 44 per 10 sec. *After physostigma*, no observation was made until the following day, when the rate was 39 per 10 sec.	*With atropia*, in 4 min. 40 sec., acceleration from 24 to 27 per 10 sec. *After physostigma*, the rate was slowed, at 34 min. to 20, and at 45 min. to 19 per 10 sec.	*With atropia*, none. *After physostigma*, in 6 and in 14 min., several normal fæcal pellets; in 48 min., several large and soft pellets; and in 1 hour 28 min., urine was voided. In 13 min., slight salivation, and soon afterwards great increase of the secretion of other buccal glands also.	*With atropia*, none. *After physostigma*, in 9 min., distinct paralysis; in 14 min., well-marked paralysis; and soon tremors and spasms also occurred. Fibrillary twitches were present for more than 2 hours in an exaggerated form.
	b 3 lbs.	0	0	1·2	Death, in 29 min.	—	—	—	—	—
93. *a* [Experiment *b* was performed eleven days after experiment *a*.]	3 lbs.	0·03	0·03	1·8	Recovery.	*With atropia*, in 3 min., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{16}{50} \times \frac{14}{50}$. *After physostigma*, in 5 min., further dilatation to $\frac{16}{50} \times \frac{15}{50}$; then contraction, until in 1 hour and 30 min., the size was $\frac{14}{50} \times \frac{14}{50}$.	*With atropia*, in 4 min., acceleration from 44 to 51 per 10 sec. *After physostigma*, slowing occurred, until in 1 hour and 30 min., the rate per 10 sec. was 32.	*With atropia*, none noted. *After physostigma*, a rapid rate was maintained until about 1 hour and 30 sec., but the rate could not be ascertained because of fibrillary twitches and frequent tremors.	*With atropia*, none. *After physostigma*, in 26 min., normal fæcal pellets and urine; and in 1 hour 20 min., wet fæces and more urine. In 31 min., salivation became evident and continued, with increased secretion from other buccal glands, until 1 hour 5 min.	*With atropia*, none. *After physostigma*, in 7 min., extension of the limbs; and in 10 min., distinct paralysis, which had diminished in 1 hour 30 min. Tremors and starts frequently occurred, and very well-marked fibrillary twitches were present.
	b 3 lbs. 2 oz.	0	0	1·25 (= 1·2 gr. p. 3 lbs.	Death, in 21 min.	—	—	—	—	—
94. *a* [Experiment *b* was performed seven days after experiment *a*.]	3 lbs. 2 oz.	0·052	0·05	1·87	Recovery.	*With atropia*, in 3 min., dilatation from $\frac{11}{50} \times \frac{10}{50}$ to $\frac{13}{50} \times \frac{13}{50}$. *After physostigma*, some further dilatation, followed by slight contraction.	*With atropia*, in 4 min., acceleration from 36 to 46 per 10 sec. *After physostigma*, no observations could be made on account of the exaggerated fibrillary twitches.	*With atropia*, none. *After physostigma*, none noted.	*With atropia*, none. *After physostigma*, none, except slight increase of salivary secretion, and this only during the first few min.	*With atropia*, none. *After physostigma*, in 9 min., slight paralysis, which, in 30 min., had become very decided, but soon after began to diminish. Fibrillary twitches were very prominent.
	b 3 lbs.	0	0	1·2	Death, in 18 min.*	—	—	—	—	—
95. *a* [Experiment *b* was performed nine days after experiment *a*.]	3 lbs. 2 oz.	0·052	0·05	1·8	Recovery.	*With atropia*, in 3 min., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{16}{50} \times \frac{16}{50}$. *After physostigma*, the above dilatation was maintained; and on the following day, was increased to $\frac{17}{50} \times \frac{17}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 45 to 54 per 10 sec. *After physostigma*, the rate per 10 sec. was maintained at about 54 for more than 45 min.	*With atropia*, none noted. *After physostigma*, none noted.	*With atropia*, none. *After physostigma*, none.	*With atropia*, none. *After physostigma*, in 10 min., decided paralysis, which had nearly disappeared at 55 min. Fibrillary twitches were prominent, and tremors and starts occurred.
	b 3 lbs. 3 oz.	0	0	1·9 (= 1·8 gr. p. 3 lbs.)	Death, in 18 min.	—	—	—	—	—

* The rabbit seemed to be in bad health when experiment *b* was performed.

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
96. *a*	3 lbs. 1 oz. [Experiment *b* was performed ten days after experiment *a*.]	1·53	1·5	1·83	Recovery.	*With atropia*, in 3 min., dilatation from $\frac{11}{50} \times \frac{10}{50}$ to $\frac{16}{50} \times \frac{16}{50}$. *After physostigma*, the above dilatation was maintained for more than 3 hours 30 min.	*With atropia*, in 4 min. 30 sec., acceleration from 39 to 50 per 10 sec. *After physostigma*, no observation was made until 2 hours, when the rate was 48 per 10 sec. In 3 hours 30 sec. it was 42 per 10 sec.	*With atropia*, in 4 min., acceleration from 17 to 20 per 10 sec. *After physostigma*, slowing occurred, and at 1 hour the rate was 14 per 10 sec.	*With atropia*, none. *After physostigma*, none. Neither defæcation nor urination occurred, nor were the secretions of the salivary or other buccal glands increased during the 3 hours and 30 min. that continuous observation lasted.	*With atropia*, none. *After physostigma*, in 8 min., slight paralysis; and in 20 min., decided paralysis. Weak starts and tremors occurred frequently after 20 min., and slight fibrillary twitches appeared in 9 min., and continued for about 30 min. A normal general condition was present in 3 hours and 30 min.
b	3 lbs. 2 oz.	0	0	1·25 (= 1·2 gr. p. 3 lbs.)	Death, in 23 min.	—	—	—	—	—
97. *a*	3 lbs. [Experiment *b* was performed nine days after experiment *a*.]	2·	2·	1·8	Recovery.	*With atropia*, in 3 min., dilatation from $\frac{15}{50} \times \frac{15}{50}$ to $\frac{17}{50} \times \frac{17}{50}$. *After physostigma*, in 2 min., further dilatation to $\frac{18}{50} \times \frac{18}{50}$, and this size was maintained for more than 3 hours.	*With atropia*, in 4 min. 10 sec., acceleration from 43 to 58 per 10 sec. *After physostigma*, no observation was made until 3 hours, when the rate was 52 per 60 sec. —On the following day, the rate was 43 per 10 sec.	*With atropia*, none noted. *After physostigma*, only a slight slowing occurred.	*With atropia*, none. *After physostigma*, none. Neither defæcation nor urination occurred, nor were the secretions of the salivary or other buccal glands increased during the 3 hours that continuous observation lasted.	*With atropia*, none. *After physostigma*, in 20 min., slight paralysis, which became pretty decided in 30 min., began to diminish in 45 min., and had disappeared in 3 hours. Slight fibrillary twitches were present for a short time after the administration of physostigma.
b	3 lbs.	0	0	1·8	Death, in 17 min.	—	—	—	—	—
98. *a*	3 lbs. 6 oz. [Experiment *b* was performed eight days after experiment *a*.]	2·92	2·6	2·02	Recovery.	*With atropia*, in 4 min., dilatation from $\frac{15}{50} \times \frac{15}{50}$ to $\frac{17}{50} \times \frac{17}{50}$. *After physostigma*, the above dilatation was maintained for several days.	*With atropia*, in 4 min. 30 sec., acceleration from 38 to 45 per 10 sec. *After physostigma*, in 3 min., there was further acceleration to 52; in 34 min., the rate per 10 sec. was 50; in 1 hour 52 min., 45; and in 2 hours 20 min., 43.—On the following day, the rate was 40 per 10 sec.	*With atropia*, in 4 min. 10 sec., acceleration from 15 to 17 per 10 sec. *After physostigma*, first slowing occurred in 24 min., to 13; and in 1 hour 15 min., to 12: afterwards, the rate increased to 15 per 10 sec.	*With atropia*, none. *After physostigma*, none. Neither defæcation nor urination occurred, nor were any secretions increased during the 2 hours and 30 min. that the observations lasted.	*With atropia*, none. *After physostigma*, in 14 min., slight paralysis, which became greater in 20 min., and had not altogether disappeared in 2 hours 30 min. Tremors and slight spasms occasionally took place. No fibrillary twitches were present after 24 min.
b	3 lbs. 6 oz.	0	0	1·35 (= 1·2 gr. p. 3 lbs.	Death, in 26 min.	—	—	—	—	—

Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
99. *a* [Experiment *b* was performed twelve days after experiment *a*.]	3 lbs. 6 oz.	3·7	3·3	2·02	Recovery.	*With atropia*, in 3 min., dilatation from $\frac{10}{50} \times \frac{9}{50}$ to $\frac{16}{50} \times \frac{15}{50}$. *After physostigma*, in 2 min., further dilatation to $\frac{17}{50} \times \frac{17}{50}$, which size was maintained for several days.	*With atropia*, in 4 min. 30 sec., acceleration from 41 to 53 per 10 sec. *After physostigma*, no observation was made until 36 min., when the rate was 49 per 10 sec.	*With atropia*, in 4 min., slowing from 20 to 18 per 10 sec. *After physostigma*, further slowing, and in 40 min. the rate was 11 per 10 sec.	*With atropia*, none. *After physostigma*, none.	*With atropia*, none. *After physostigma*, in 10 min., slight paralysis; in 30 min., decided paralysis, which, though diminished, continued for more than 1 hour and 40 min. Slight tremors and starts occurred. Fibrillary twitches were present for only a short time at the commencement.
b	3 lbs. 9 oz.	0	0	1·4(=1·2 gr. p. 3 lbs.)	Death, in 30 min.	—	—	—	—	—
100. *a* [Experiment *b* was performed twelve days after experiment *a*.]	3 lbs. 2 oz.	4·27	4·1	1·87	Recovery.	*With atropia*, in 4 min. 30 sec., dilatation from $\frac{13}{50} \times \frac{11}{50}$ to $\frac{17}{50} \times \frac{17}{50}$. *After physostigma*, the above dilatation was maintained for more than 2 hours.	*With atropia*, in 4 min., acceleration from 39 to 56 per 10 sec. *After physostigma*, slowing occurred; the rate per 10 sec. was in 37 min., 41; and in 2 hours, 37.—On the following day the rate was 44 per 10 sec.	*With atropia*, in 3 min. 30 sec., slowing from 17 to 9 per 10 sec. *After physostigma*, no material change occurred.	*With atropia*, none. *After physostigma*, none.	*With atropia*, none. *After physostigma*, in 7 min., slight paralysis; in 12 min., decided paralysis, which had not disappeared in 2 hours 37 min. Fibrillary twitches were present during only the first 10 min. No tremors nor starts.
b	3 lbs. 4 oz.	0	0	1·3 (= 1·2 gr. p. 3 lbs.	Death, in 19 min.	—	—	—	—	—
101.	3 lbs. 1 oz.	4·38	4·3	1·83	Death, in 1 hour and 26 min. after the administration of physostigma.	*With atropia*, in 4 min. 30 sec., dilatation from $\frac{10}{50} \times \frac{9}{50}$ to $\frac{16}{50} \times \frac{16}{50}$. *After physostigma*, the size continued at $\frac{16}{50} \times \frac{16}{50}$ until death.	*With atropia*, in 4 min., acceleration from 32 to 49 per 10 sec. *After physostigma*, the rate per 10 sec. was in 37 min., 45; in 52 min., 38; in 1 hour, 34; and in 1 hour 20 min., 18.	*With atropia*, none. *After physostigma*, slowing from the original rate per 10 sec. of 14, to, in 10 min., 11; in 40 min., 9; and in 1 hour and 20 min., 3.	*With atropia*, none. *After physostigma*, in 4 min., several normal fæcal pellets; otherwise no effect on secretion or excretion.	*With atropia*, none. *After physostigma*, in 9 min., slight paralysis; and in 20 min., decided paralysis, which increased until death. Tremors and weak spasms occurred frequently, and fibrillary twitches during only the first 30 min.

TABLE 4.—EXPERIMENT WITH TWICE THE MINIMUM-LETHAL DOSE OF PHYSOSTIGMA (2·4 *grs. of Extract of Physostigma per Three Pounds Weight of Rabbit*).

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains.) Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
102.	3 lbs. 3 oz.	0·02	0·019	2·6	Death, in 39 min. after the administration of physostigma.	*With atropia*, in 4 min., dilatation from $\frac{16}{50} \times \frac{14}{50}$ to $\frac{18}{50} \times \frac{18}{50}$. *After physostigma*, in 3 min., further dilatation to $\frac{18}{50} \times \frac{18}{50}$; afterwards contraction—in 16 min., to $\frac{13}{50} \times \frac{12}{50}$; and in 24 min. to $\frac{7}{50} \times \frac{6}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 45 to 54 per 10 sec. *After physostigma*, no observations were made on account of the severity of the general symptoms.	*With atropia*, none. *After physostigma*, no exact observations were made until 25 min., when slowing had occurred to 8 per 10 sec.; in 30 min. to 6; and in 34 min. to 5 feeble gasps per 10 sec.	*With atropia*, none. *After physostigma*, none.	*With atropia*, none. *After physostigma*, in 8 min., tremors and distinct paralysis: the latter increased until death; the former were very severe until 24 min., and they then became less so, but continued until death. Fibrillary twitches appeared very early, became prominently developed, and continued so until death.
103.	3 lbs.	0·02	0·02	2·4	Death, in 42 min. after the administration of physostigma.	*With atropia*, in 4 min., dilatation from $\frac{16}{50} \times \frac{14}{50}$ to $\frac{17}{50} \times \frac{17}{50}$. *After physostigma*, the size was in 12 min., $\frac{17}{50} \times \frac{17}{50}$; in 17 min., $\frac{14}{50} \times \frac{13}{50}$; and in 19 min., $\frac{10}{50} \times \frac{9}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 45 to 52 per 10 sec. *After physostigma*, no observations were made on account of the severity of the general symptoms.	*With atropia*, none. *After physostigma*, the rate was in 20 min., 13 per 10 sec., and shallow and interrupted by tremors; and in 32 min., 6 per 10 sec.	*With atropia*, none. *After physostigma*, in 20 min., several normal fæcal pellets. No salivation occurred, nor was increase of the secretion of any gland observed.	*With atropia*, none. *After physostigma*, in 8 min., decided paralysis, and soon afterwards tremors occurred. Fibrillary twitches were present until death.
104.	2 lbs. 15 oz.	0·02	0·02	2·35	Death, in 39 min. after the administration of physostigma.	*With atropia*, in 4 min., dilatation from $\frac{11}{50} \times \frac{10}{50}$ to $\frac{12}{50} \times \frac{11}{50}$. *After physostigma*, the size was in 6 min., $\frac{15}{50} \times \frac{15}{50}$; in 11 min., $\frac{14}{50} \times \frac{14}{50}$; in 16 min., $\frac{12}{50} \times \frac{12}{50}$; and in 31 min., $\frac{5}{50} \times \frac{4}{50}$.—After death, in 2 min., $\frac{5}{50} \times \frac{4}{50}$; and in 8 min., $\frac{11}{50} \times \frac{10}{50}$.	*With atropia*, in 4 min. 40 sec., acceleration from 45 to 46 per 10 sec. *After physostigma*, no observations were made on account of the severity of the general symptoms.	*With atropia*, none. *After physostigma*, first, acceleration; and afterwards slowing, which latter continued until death.	*With atropia*, none. *After physostigma*, in 15 min., defæcation and salivation; the latter soon increased, and along with an increase in the secretion of other buccal glands, greatly embarrassed the respiratory movements.	*With atropia*, none. *After physostigma*, in 7 min., distinct paralysis; and in 15 min., decided paralysis; along with which, in 18 min., tremors, which often recurred until death. Fibrillary twitches soon became prominently developed, and continued so until death.
105.	3 lbs. 7 oz.	0·025	0·021	2·7	Death, in 25 min. after the administration of physostigma.	*With atropia*, none observed. *After physostigma*, in 3 min., dilatation from original size of $\frac{15}{50} \times \frac{14}{50}$ to $\frac{18}{50} \times \frac{18}{50}$; in 8 min., contraction to $\frac{13}{50} \times \frac{13}{50}$; and in 11 min., to $\frac{5}{50} \times \frac{4}{50}$.	*With atropia*, none observed. *After physostigma*, in 4 min., slowing from the original rate per 10 sec. of 33 to that of 26. Further observations were not made on account of the severity of the general symptoms.	*With atropia*, in 4 min., acceleration from 18 to 22 per 10 sec. *After physostigma*, in 18 min., slowing to 16 per 10 sec.; in 21 min., 8 laboured and noisy gasps per 10 sec.; and in 24 min., 2 laboured and feeble gasps per 10 sec.	*With atropia*, none. *After physostigma*, in 8 min., increased secretion from buccal glands, and soon afterwards salivation, both of which continued until death. Neither defæcation nor urination occurred.	*With atropia*, none. *After physostigma*, in 7 min., slight paralysis; and in 9 min., decided paralysis, which soon became accompanied with tremors and spasms. Fibrillary twitches early became prominent, and continued until death.

Number of Experiment.	Weight of Rabbit.	phate of Atropia (in Grains). Actual Dose.	phate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
106. *a* [Experiment *b* was performed seven days after experiment *a*.]	3 lbs.	0·025	0·025	2·4	Recovery.	*With atropia*, in 4 min. 30 sec., dilatation from $\frac{14}{50} \times \frac{18}{50}$ to $\frac{16}{50} \times \frac{16}{50}$. *After physostigma*, in 3 min., further dilatation to $\frac{18}{50} \times \frac{18}{50}$, which size continued for more than 2 hours.—On the following day the size was $\frac{12}{50} \times \frac{11}{50}$.	*With atropia*, in 4 min. 40 sec., acceleration from 43 to 50 per 10 sec. *After physostigma*, in 5 min., further acceleration to 52, which rate was maintained for 1 hour 40 min.—On the following day, the rate per 10 sec. was 30.	*With atropia*, none observed. *After physostigma*, a slight slowing occurred.	*With atropia*, none. *After physostigma*, none observed.	*With atropia*, none. *After physostigma*, in 7 min., slight paralysis and tremors; and in 10 min., slight paralysis, tremors, and spasms. The paralysis and spasms continued until 1 hour and 25 min., when they began to diminish, and had almost disappeared at 1 hour 40 min. Fibrillary twitches early became prominent, and continued for more than 26 hours, though latterly in only a slight form.
	3 lbs.	0	0	1·2	Death, in 12 min.	—	—	—	—	—
107.	3 lbs.	0·03	0·03	2·4	Death, in 13 min. after the administration of physostigma.	*With atropia*, in 4 min., dilatation from $\frac{10}{50} \times \frac{9}{50}$ to $\frac{12}{50} \times \frac{11}{50}$. *After physostigma*, in 6 min., further dilatation to $\frac{15}{50} \times \frac{15}{50}$; and then contraction, in 10 min., to $\frac{6}{50} \times \frac{5}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 36 to 42 per 10 sec. *After physostigma*, no observation was made on account of the severity of the general symptoms.	*With atropia*, none observed. *After physostigma*, at first, acceleration, and then slowing.	*With atropia*, none. *After physostigma*, none observed.	*With atropia*, none. *After physostigma*, in 8 min., very energetic and excited movements, followed in 10 min. by exhaustion and flaccidity. Fibrillary twitches were but slightly developed.
108. *a* [Experiment *b* was performed six days after experiment *a*.]	2 lbs. 15 oz.	0·04	0·04	2·35	Recovery.	*With atropia*, in 3 min., dilatation from $\frac{13}{50} \times \frac{12}{50}$ to $\frac{14}{50} \times \frac{14}{50}$. *After physostigma*, in 2 min., further dilatation to $\frac{17}{50} \times \frac{17}{50}$, which size continued for more than 1 hour 30 min.—On the following day, the size was $\frac{16}{50} \times \frac{16}{50}$; and on the 3d day, $\frac{14}{50} \times \frac{13}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 39 to 43 per 10 sec. *After physostigma*, no observations were made until 1 hour 20 min., when the rate was 44 per 10 sec.	*With atropia*, none observed. *After physostigma*, no marked effect was produced.	*With atropia*, none. *After physostigma*, in 5 min., slight increase of buccal secretions, but this ceased in 15 min. No defæcation nor urination for more than 1 hour 30 min.	*With atropia*, none. *After physostigma*, in 6 min., slight paralysis; and in 23 min., decided paralysis, which in 50 min. had greatly diminished. Fibrillary twitches early appeared, and continued for more than 1 hour and 20 min.
	3 lbs.	0	0	1·2	Death, in 14 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal	Dose of Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
109. *a*	3 lbs. 1 oz. [Experiment *b* was performed six days after experiment *a*.]	0·05	0·05	2·45	Recovery.	*With atropia*, in 3 min. 30 sec., dilatation from $\frac{11}{50} \times \frac{10}{50}$ to $\frac{14}{50} \times \frac{14}{50}$. *After physostigma*, in 3 min., further dilatation to $\frac{15}{50} \times \frac{15}{50}$, which continued for more than 2 hours 30 min.—On the following day the size was $\frac{14}{50} \times \frac{14}{50}$; and on the 5th day, $\frac{11}{50} \times \frac{10}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 39 to 49 per 10 sec. *After physostigma*, no observations could be made until 1 hour 25 min., when the rate per 10 sec. was 49; in 2 hours it was 48; and in 2 hours 20 min., 48.—On the following day the rate per 10 sec. was 29; on the 5th day, 39; and on the 6th day, 40.	*With atropia*, in 3 min., acceleration from 29 to 33 per 10 sec. *After physostigma*, slowing occurred until in 1 hour 25 min., the rate per 10 sec. was 23; in 2 hours it was 21; and in 2 hours 20 min., 22.—On the following day the rate per 10 sec. was 20; and on the 6th day, 21.	*With atropia*, none. *After physostigma*, none. Neither defæcation nor urination occurred for more than 2 hours 30 min., nor was the secretion of the salivary or other buccal glands increased.	*With atropia*, none. *After physostigma*, in 6 min., slight paralysis, which, gradually increasing, reached its height in 25 min., and began to diminish in 50 min. Tremors occurred during this time; and fibrillary twitches appeared in a prominent form, and continued for more than 2 hours and 20 min.
b	3 lbs.	0	0	1·2	Death, in 23 min.	—	—	—	—	—
110 *a*	3 lbs. 2 oz. [Experiment *b* was performed ten days after experiment *a*.]	0·31	0·3	2·5	Recovery.	*With atropia*, in 3 min., dilatation from $\frac{13}{50} \times \frac{12}{50}$ to $\frac{15}{50} \times \frac{15}{50}$. *After physostigma*, in 2 min., further dilatation to $\frac{18}{50} \times \frac{18}{50}$, which remained for more than 1 hour 20 min.—On the following day the size was $\frac{17}{50} \times \frac{17}{50}$; on the 4th day, $\frac{14}{50} \times \frac{13}{50}$; and on the 6th day, $\frac{13}{50} \times \frac{12}{50}$.	*With atropia*, in 3 min. 30 sec., acceleration from 45 to 56 per 10 sec. *After physostigma*, no observations were made until the following day, when the rate per 10 sec. was 46; on the 3d day it was 38; and on the 4th day, 40.	*With atropia*, none observed. *After physostigma*, no observations were made.	*With atropia*, none. *After physostigma*, none observed during the following 2 hours.	*With atropia*, none. *After physostigma*, in 16 min., distinct paralysis; and in 22 min., well-marked paralysis. No tremors were observed durthe 2 hours that the observations lasted. Fibrillary twitches early became prominent, and continued so for more than 1 hour and 50 min.
b	3 lbs. 4 oz.	0	0	1·3 (= 1·2 gr. p. 3 lbs.)	Death, in 18 min.	—	—	—	—	—
111. *a*	2 lbs. 15½ oz. [Experiment *b* was performed eleven days after experiment *a*.]	1·	1·	2·4	Recovery.	*With atropia*, in 2 min. 30 sec., dilatation from $\frac{10}{50} \times \frac{9}{50}$ to $\frac{14}{50} \times \frac{14}{50}$. *After physostigma*, in 2 min., further dilatation to $\frac{18}{50} \times \frac{18}{50}$; in 16 min., contraction to $\frac{15}{50} \times \frac{15}{50}$; in 30 min., to $\frac{13}{50} \times \frac{13}{50}$; in 40 min., to $\frac{12}{50} \times \frac{12}{50}$; and in 1 hour, to $\frac{10}{50} \times \frac{9}{50}$, which size was continued until at least 2 hours 20 min.—On the following day the size was $\frac{12}{50} \times \frac{11}{50}$; and on the 4th day, $\frac{11}{50} \times \frac{10}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 41 to 52 per 10 sec. *After physostigma*, in 7 min., the rate per 10 sec. was 53; in 35 min., 53; in 1 hour, 37; in 1 hour 30 min., 28; and in 2 hours 25 min., 27.—On the following day the rate per 10 sec. was 52; on the 3d day, 45; and on the 4th day, 41.	*With atropia*, none. *After physostigma*, in 14 min., slowing from the original rate of 20 per 10 sec. to 15; and in 1 hour 30 min. the rate per 10 sec. was 14.—On the following day the rate per 10 sec. was 18; and on the 4th day, 20.	*With atropia*, none. *After physostigma*, several normal fæcal pellets were passed in 48 min., and also in 1 hour. In 1 hour 8 min., wet fæcal pellets and urine; and after 2 hours occasionally a few drops of urine were voided. The secretion of the buccal glands was not increased.	*With atropia*, none. *After physostigma*, in 12 min., slight paralysis; in 30 min., decided though not very great paralysis; and in 1 hour, decided diminution in the paralysis, which had almost disappeared in 1 hour and 20 min. No tremors nor spasms occurred. Fibrillary twitches early became developed, but had nearly disappeared in 1 hour 20 min.
b	2 lbs. 15¾ oz.	0	0	2·35 (= 2·4 grs. p. 3 lbs.)	Death, in 10 min.	—	—	—	—	—

Number of Experiment.		Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
112.	*a*	3 lbs. [Experiment *b* was performed nineteen days after experiment *a*.]	2·	2·	2·4	Recovery.	*With atropia*, in 4 min., dilatation from $\frac{15}{60} \times \frac{14}{60}$ to $\frac{17}{60} \times \frac{17}{60}$. *After physostigma*, the size continued at $\frac{17}{60} \times \frac{17}{60}$ for the next 4 hours. —On the following day it was $\frac{17}{60} \times \frac{17}{60}$; on the 7th day, $\frac{17}{60} \times \frac{17}{60}$; on the 8th day, $\frac{16}{60} \times \frac{16}{60}$; and on the 20th day, $\frac{16}{60} \times \frac{16}{60}$.	*With atropia*, in 4 min. 30 sec., acceleration from 42 to 59 per 10 sec. *After physostigma*, slowing occurred, and the rate per 10 sec. was in 2 hours, 37.—On the following day it was 36; and on the 3d day, 40.	*With atropia*, none noted. *After physostigma*, slowing occurred from the original rate per 10 sec. of 22 to in 30 min., 14; and in 1 hour, 11.—Afterwards acceleration occurred, and in 2 hours the rate was 16 per 10 sec.	*With atropia*, none. *After physostigma*, in 2 hours, urine was voided, and some slightly pultaceous fæces; and this was repeated in 2 hours 15 min., and in 3 hours 30 min. In 2 hours 40 min., some moist sounds were heard with respiration; otherwise, no increase in secretion of any buccal glands.	*With atropia*, none. *After physostigma*, in 20 min., weakness; in 23 min., slight paralysis; and in 30 min., decided though not severe paralysis. The paralysis began to diminish in 1 hour 40 min., and had disappeared by 2 hours 40 min. Very gentle tremors twice occurred. Fibrillary twitches early became pretty well marked, they, however, had diminished in 40 min., but were still present in 4 hours 10 min.
	b	3 lbs.	0	0	1·2	Death, in 17 min.	—	—	—	—	—
113.	*a*	3 lbs. 4 oz. [Experiment *b* was performed eleven days after experiment *a*.]	2·49	2·3	2·6	Recovery.	*With atropia*, in 4 min., dilatation from $\frac{13}{60} \times \frac{12}{60}$ to $\frac{16}{60} \times \frac{16}{60}$. *After physostigma*, the dilatation increased to $\frac{18}{60} \times \frac{18}{60}$, and this size was maintained. — On the following day, the size was $\frac{19}{60} \times \frac{19}{60}$; on the 9th day, $\frac{16}{60} \times \frac{16}{60}$; and on the 12th day, $\frac{15}{60} \times \frac{14}{60}$.	*With atropia*, in 4 min. 10 sec., acceleration from 39 to 50 per 10 sec. *After physostigma*, the condition of the animal prevented accurate observations being made. —On the following day, the rate per 10 sec. was 25, and their occurrence irregular; on the 4th day, the rate per 10 sec. was 29; and on the 8th day, 43.	*With atropia*, in 4 min. 40 sec., acceleration from 26 to 32 per 10 sec. *After physostigma*, in 15 min., further acceleration to 40 per 10 sec.; then slowing, in 28 min., to 20; and in 1 hour, to 16.	*With atropia*, none. *After physostigma*, in 4 min., several normal fæcal pellets were passed. No salivation nor increase of any buccal secretion occurred, during the 2 hours 10 min. of continuous observation.	*With atropia*, none. *After physostigma*, in 9 min., weakness; and in 15 min., decided though not severe paralysis. The paralysis increased until about 40 min., but had diminished in 1 hour and 10 min., and was only very slight in 2 hours. Tremors and spasms frequently occurred. Fibrillary twitches were present during only the first 35 min.
	b	3 lbs. 3 oz.	0	0	1·28 (= 1·2 gr. p. 3 lbs.)	Death, in 25 min.	—	—	—	—	—
114.	*a*	3 lbs. [Experiment *b* was performed nine days after experiment *a*.]	3·	3·	2·4	Recovery.	*With atropia*, in 4 min. 30 sec., dilatation from $\frac{11}{60} \times \frac{10}{60}$ to $\frac{15}{60} \times \frac{15}{60}$. *After physostigma*, the size remained $\frac{15}{60} \times \frac{15}{60}$. —On the following day, it was $\frac{15}{60} \times \frac{15}{60}$; on the 4th day, $\frac{14}{60} \times \frac{14}{60}$; and on the 7th day, $\frac{12}{60} \times \frac{11}{60}$.	*With atropia*, none noted. *After physostigma*, no observations were made until the following day, when the rate per 10 sec. was 51; on the 4th day, it was 46; and on the 7th day, 41.	*With atropia*, none noted. *After physostigma*, slowing from the original rate of 30 per 10 sec. took place, and in 1 hour the rate per 10 sec. was 20.	*With atropia*, none. *After physostigma*, a little urine was twice voided, but no defæcation nor increase in the secretion of any buccal gland occurred.	*With atropia*, none. *After physostigma*, in 15 min., slight paralysis, which gradually increased until flaccidity was nearly present in 50 min.; it afterwards gradually diminished, until it had almost disappeared in 2 hours 40 min. Slight tremors occasionally occurred. Fibrillary twitches early appeared; they had nearly disappeared by 50 min., but again appeared in a well-marked form in 1 hour 40 min.
	b	3 lbs. 1 oz.	0	0	1·22 (= 1·2 gr. p. 3 lbs.)	Death, in 27 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
115. *a* [Experiment *b* was performed fifteen days after experiment *a*.—The animal was a common wild rabbit.]	3 lbs. 5 oz.	3·53	3·2	2·65	Recovery.	*With atropia*, dilatation occurred. *After physostigma*, further dilatation occurred.	*With atropia*, acceleration occurred. *After physostigma*, none noted.	*With atropia*, none noted. *After physostigma*, slowing occurred, and in 1 hour the rate per 10 sec. was 14—the rate having originally been 22 per 10 sec.	*With atropia*, none. *After physostigma*, none.	*With atropia*, none. *After physostigma*, in 30 min., slight paralysis; which increased and became most marked, though not very severe, in 55 min.; but had disappeared by 2 hours 40 min. Neither spasms nor tremors occurred. Fibrillary twitches were well marked in 14 min., but soon afterwards lessened, and became very slight.
b	3 lbs. 4 oz.	0	0	2·6 (= 2·4 grs. p. 3 lbs.)	Death, in 10 min.	—	—	—	—	—
116.	2 lbs. 15 oz.	3·23	3·3	2·35	Death, in 1 hour 11 min. after the administration of physostigma.	*With atropia*, in 3 min., dilatation from $\frac{13}{50} \times \frac{12}{50}$ to $\frac{16}{50} \times \frac{15}{50}$. *After physostigma*, in 2 min., further dilatation to $\frac{16}{50} \times \frac{16}{50}$, which size remained until death.—After death, in 4 min., contraction had taken place to $\frac{14}{50} \times \frac{14}{50}$; and in 30 min., the size was still $\frac{14}{50} \times \frac{14}{50}$.	*With atropia*, in 4 min., acceleration from 42 to 50 per 10 sec. *After physostigma*, slowing occurred, in 16 min., to 42; and in 57 min. to 31 per 10 sec., after which observations were not made, in order to avoid interference with the respiratory movements.	*With atropia*, in 4 min. 20 sec., slowing from 21 to 19 per 10 sec. *After physostigma*, in 6 min., acceleration to 31 per 10 sec.; and afterwards slowing—in 15 min., to 16; in 1 hour, to 10; in 1 hour 12 min., to 4; and then mere gasps occurred until death.	*With atropia*, none. *After physostigma*, in 17 min., several fæcal pellets were passed for the first and only time. No urination occurred, nor was the secretion of any buccal gland increased.	*With atropia*, none. *After physostigma*, in 9 min., slight paralysis; and in 12 min., decided paralysis, which gradually increased until death. No tremors occurred. Fibrillary twitches were only very slightly developed.
117.	3 lbs.	3·5	3·5	2·4	Death, in 54 min. after the administration of physostigma.	*With atropia*, in 3 min., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{18}{50} \times \frac{18}{50}$. *After physostigma*, the size remained $\frac{18}{50} \times \frac{18}{50}$ until death. — After death, contraction took place, in 3 min., to $\frac{15}{50} \times \frac{16}{50}$; in 6 min., to $\frac{14}{50} \times \frac{14}{50}$; in 14 min., to $\frac{12}{50} \times \frac{12}{50}$; and this last size remained for more than other 50 min.	*With atropia*, in 4 min., acceleration from 40 to 58 per 10 sec. *After physostigma*, in 4 min., further acceleration occurred to 60 per 10 sec. Afterwards, slowing took place—in 30 min. to 58, and in 48 min., to 32 per 10 sec.	*With atropia*, none noted. *After physostigma*, slowing took place from the original rate of 22 per 10 sec., to, in 27 min., 10 per 10 sec.; in 43 min., 4 gasps per 10 sec.; and in 53 min., 2 gasps per 10 sec.	*With atropia*, none. *After physostigma*, none.	*With atropia*, none. *After physostigma*, in 10 min., decided paralysis, which increased until death. Feeble tremors and weak spasms early occurred. Very slight fibrillary twitches were seen during the first 10 min. after the administration of physostigma, but they thereafter disappeared.

TABLE 5.—EXPERIMENTS WITH [illegible] (*Weight of Rabbit*).

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal	Dose of Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
118.	3 lbs. 5 oz.	0·012	0·011	3·3	Death, in 20 min. after the administration of physostigma.	*With atropia*, in 4 min., dilatation from $\frac{11}{50} \times \frac{10}{50}$ to $\frac{14}{50} \times \frac{13}{50}$. *After physostigma*, in 4 min., further dilatation to $\frac{15}{50} \times \frac{15}{50}$, which remained until 9 min.; contraction soon after occurred, in 10 min. to $\frac{13}{50} \times \frac{13}{50}$; in 11 min. to $\frac{9}{50} \times \frac{8}{50}$; in 15 min. to $\frac{4}{50} \times \frac{3}{50}$; and in 18 min. to $\frac{3}{50} \times \frac{3}{50}$.	*With atropia*, none. *After physostigma*, slowing occurred from the original rate per 10 sec. of 39; in 5 min. to 33; and in 16 min. to 12.	*With atropia*, none. *After physostigma*, the condition of the rabbit prevented accurate observations from being made.	*With atropia*, none. *After physostigma*, in 10 min., normal fæces; in 13 min., salivation, which soon became profuse, and along with an increased secretion of other buccal (and of bronchial?) glands greatly impeded respiration.	*With atropia*, none. *After physostigma*, in 5 min., some stiff extension of the limbs occurred, after which paralysis appeared and increased until death. In 11 min. and frequently afterwards, tremors took place. Fibrillary twitches were early present in a well-marked form.
119.	3 lbs.	0·0187	0·0187	3·	Death, in 28 min. after the administration of physostigma.	*With atropia*, in 4 min., dilatation from $\frac{11}{50} \times \frac{10}{50}$ to $\frac{13}{50} \times \frac{12}{50}$. *After physostigma*, in 5 min., further dilatation to $\frac{15}{50} \times \frac{15}{50}$, and soon afterwards contraction commenced. In 8 min. the size was $\frac{10}{50} \times \frac{10}{50}$; in 9 min., $\frac{7}{50} \times \frac{6}{50}$; and in 27 min., $\frac{5}{50} \times \frac{4}{50}$.—After death the size of $\frac{5}{50} \times \frac{4}{50}$ remained for more than 18 min.	*With atropia*, none. *After physostigma*, slowing occurred from the original rate per 10 sec. of 38, to in 5 min., 31; and in 24 min., 11 per 10 sec.	*With atropia*, none. *After physostigma*, slowing occurred, and the rate per 10 sec. was in 21 min., 10; in 15 min., 3; and afterwards only feeble irregular gasps occurred.	*With atropia*, none. *After physostigma*, neither defæcation nor urination occurred; but the secretion of the buccal glands was increased in 11 min. as then moist sounds accompanied the respirations, and continued to do so until death.	*With atropia*, none. *After physostigma*, in 6 min., slight paralysis appeared, which soon became well marked, and increased until death. Tremors and weak spasms frequently occurred, and fibrillary twitches were prominently developed.
120.	3 lbs.	0·025	0·025	3·	Death, in 1 hour 6 min. after the administration of physostigma.	*With atropia*, in 4 min. 30 sec., dilatation from $\frac{15}{50} \times \frac{15}{50}$ to $\frac{18}{50} \times \frac{18}{50}$. *After physostigma*, in 8 min. the size was $\frac{17}{50} \times \frac{17}{50}$; in 41 min., $\frac{14}{50} \times \frac{14}{50}$; in 50 min., $\frac{10}{50} \times \frac{10}{50}$; and in 52 min., $\frac{17}{50} \times \frac{17}{50}$, which size remained until death. — After death in 4 min., the size was $\frac{13}{50} \times \frac{13}{50}$; and in 14 min., $\frac{12}{50} \times \frac{12}{50}$.	*With atropia*, none noted. *After physostigma*, in 45 min., slowing had occurred from the original rate of 41 to 32 per 10 sec.; in 54 min. the rate per 10 sec. was 31; in 1 hour, 27; and in 1 hour 5 min., only rare and very feeble impulses could be felt.	*With atropia*, none. *After physostigma*, slowing occurred. In 40 min. the rate per 10 sec. was 8; in 47 min., 5; and in 54 min., 13. The movements in 54 min. were feeble and gasping, and they continued so until death.	*With atropia*, none. *After physostigma*, none. Neither defæcation nor urination occurred, and there was no evidence of an increase in the secretion of any buccal gland, excepting that at 7 min. after the administration of physostigma, movements of the lips and mouth occurred.	*With atropia*, none. *After physostigma*, in 9 min., decided paralysis, which increased until death, flaccidity being present in 48 min. Slight tremors and starts occasionally took place. Fibrillary twitches were prominent during the greater part of the experiment, but they had almost disappeared in 50 min. after the administration of physostigma.

Number of Experiment.		Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
121.	*a*	3 lbs. [Experiment *b* was performed six days after experiment *a*.]	0·025	0·025	3·	Recovery.	*With atropia*, in 3 min., dilatation from $\frac{13}{50} \times \frac{12}{50}$ to $\frac{15}{50} \times \frac{15}{50}$. *After physostigma*, in 7 min., further dilatation to $\frac{18}{50} \times \frac{18}{50}$, and this size was maintained for more than 1 hour, but in 1 hour 14 min., contraction to $\frac{16}{50} \times \frac{16}{50}$ had occurred.—On the following day the size was $\frac{16}{50} \times \frac{14}{50}$; and on the 4th day, $\frac{13}{50} \times \frac{12}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 39 to 45 per 10 sec. *After physostigma*, in 30 min., the rate per 10 sec. was 44.—On the following day it was 36.	*With atropia*, none. *After physostigma*, slowing occurred; and in 20 min. the rate per 10 sec. was 17.	*With atropia*, none. *After physostigma*, in 16 min., urine was voided. In 15 min., moist sounds accompanied the respirations and indicated an increase in the secretion of the buccal glands; but these sounds had ceased in 20 min., and they did not recur.	*With atropia*, none. *After physostigma*, in 7 min., decided paralysis; and in 18 min., general flaccidity, which continued along with tremors until 1 hour, after which the paralysis and tremors diminished, and they had almost disappeared in 2 hours. Fibrillary twitches were present in a very prominent form for more than 2 hours.
	b	3 lbs.	0	0	1·2	Death, in 24 min.	—	—	—	—	—
122.	*a*	4 lbs. 2 oz. [Experiment *b* was performed eleven days after experiment *a*.]	0·037	0·027	4·1	Recovery.	*With atropia*, none noted. *After physostigma*, in 6 min., dilatation from the original size of $\frac{12}{50} \times \frac{11}{50}$ to $\frac{16}{50} \times \frac{16}{50}$; and in 10 min. to $\frac{17}{50} \times \frac{17}{50}$. In 1 hour the size was again $\frac{15}{50} \times \frac{15}{50}$.	*With atropia*, in 4 min. 40 sec., acceleration from 42 to 55 per 10 sec. *After physostigma*, no observation was made until 40 min., when the rate per 10 sec. was 57; and in 1 hour 30 min., it was 54.—On the following day the rate per 10 sec. was 39; and on the 3d day, 41.	*With atropia*, in 4 min., acceleration from 25 to 30 per 10 sec. *After physostigma*, the acceleration was maintained until more than 20 min. after the administration of physostigma.	*With atropia*, none. *After physostigma*, in 2 hours, wet fæcal pellets were passed. No salivation nor increase of the secretion of any buccal gland occurred, excepting that during a few minutes after the administration of physostigma movements were made of the mouth and lips.	*With atropia*, none. *After physostigma*, in 8 min., slight paralysis; and in 10 min., decided paralysis, which increased until 50 min. Soon after the paralysis diminished, and it had almost disappeared in 3 hours. Tremors and weak spasms frequently occurred, and fibrillary twitches were very well marked during the greater part of the experiment.
	b	4 lbs. 3 oz.	0	0	2·1 (= 1·5 gr. p. 3 lbs.)	Death, in 15 min.	—	—	—	—	—
123.	*a*	2 lbs. 15 oz. [Experiment *b* was performed nine days after experiment *a*.]	0·025	0·028	3·	Recovery.	*With atropia*, in 3 min., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{15}{50} \times \frac{15}{50}$. *After physostigma*, in 2 min., further dilatation to $\frac{17}{50} \times \frac{17}{50}$; and then, in 1 hour, contraction to $\frac{15}{50} \times \frac{15}{50}$.	*With atropia*, in 4 min., acceleration from 39 to 47 per 10 sec. *After physostigma*, in 1 hour, slowing to the rate per 10 sec. of 44; and in 2 hours, to that of 37. This reduced rate continued for more than 5 days.	*With atropia*, none. *After physostigma*, slowing occurred from the original rate of 18 per 10 sec. in 1 hour to 15; and this rate continued for more than 2 hours afterwards.	*With atropia*, none. *After physostigma*, none, excepting a slight increase in the secretions of the buccal glands for a few minutes after physostigma had been injected. There was no defæcation nor urination during the 3 hours of continuous observation.	*With atropia*, none. *After physostigma*, in 10 min., decided paralysis, which became very great, and was still marked, though diminished, in 3 hours, after which the observations were stopped. Tremors and weak spasms occurred pretty frequently, and fibrillary twitches were well developed.
	b	3 lbs.	0	0	1·2	Death, in 12 min.	—	—	—	—	—

Number of Experiment.		Weight of Rabbit.	Sulphate of Atropia (in Grains). Actual Dose.	Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
124. [Experiment *b* was performed nine days after experiment *a*.]	*a*	3 lbs. 4 oz.	0·0375	0·034	3·25	Recovery.	*With atropia*, in 3 min. 30 sec., dilatation from $\frac{10}{50} \times \frac{9}{50}$ to $\frac{13}{50} \times \frac{13}{50}$. *After physostigma*, in 2 min., further dilatation to $\frac{16}{50} \times \frac{16}{50}$; in 20 min., contraction to $\frac{15}{50} \times \frac{15}{50}$; and in 1 hour 40 min., to $\frac{14}{50} \times \frac{14}{50}$.—On the following day, the size was $\frac{12}{50} \times \frac{11}{50}$; and on the 3d day, $\frac{10}{50} \times \frac{9}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 37 to 46 per 10 sec. *After physostigma*, no observation could be made until 56 min., when the rate per 10 sec. was 38, and this rate was continued for more than 1 hour.—On the following day, the rate per 10 sec. was 35; on the 3d day, 39.	*With atropia*, none. *After physostigma*, no accurate observations could be made on account of the twitches and tremors, during the period of continuous observation.	*With atropia*, none. *After physostigma*, none during the 2 hours of continuous observation.	*With atropia*, none. *After physostigma*, in 8 min., slight paralysis; and in 25 min., severe paralysis, which, though diminished, had not disappeared in 2 hours. Tremors and weak spasms frequently occurred, and fibrillary twitches were well developed.
	b	3 lbs. 4 oz.	0	0	1·3 (= 1·2 gr. p. 3 lbs.	Death, in 19 min.	—	—	—	—	—
125. [Experiment *b* was performed seven days after experiment *a*.]	*a*	3 lbs.	0·0375	0·0375	3·	Recovery.	*With atropia*, none noted. *After physostigma*, in 4 min., dilatation from the original size of $\frac{12}{50} \times \frac{11}{50}$ to $\frac{17}{50} \times \frac{17}{50}$. The latter size remained until 1 hour 15 min. Subsequently, a little contraction occurred; and in 1 hour 45 min., the size was $\frac{15}{50} \times \frac{15}{50}$.—On the following day, the size was $\frac{15}{50} \times \frac{15}{50}$; and on the 3d day, $\frac{13}{50} \times \frac{12}{50}$.	*With atropia*, none noted. *After physostigma*, the rate per 10 sec. could not be ascertained on account of tremors and twitches.—On the following day, it was 34 per 10 sec.; and on the 3d day, 37.	*With atropia*, none. *After physostigma*, none noted.	*With atropia*, none. *After physostigma*, in 45 min., a small quantity of urine was voided almost *guttatim*; and in 59 min. a further quantity freely. No salivation occurred, nor was there any evidence of an increase in the secretion of any gland.	*With atropia*, none. *After physostigma*, in 9 min., slight paralysis; in 27 min., pretty decided paralysis; and in 1 hour 45 min., only a little weakness. Tremors and weak spasms frequently occurred, and fibrillary twitches were present in a prominent form until after 2 hours.
	b	3 lbs.	0	0	1·5	Death, in 21 min.	—	—	—	—	—
126. [Experiment *b* was performed seven days after experiment *a*.]	*a*	3 lbs.	0·05	0·05	3·	Recovery.	*With atropia*, in 4 min., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{17}{50} \times \frac{17}{50}$. *After physostigma*, in 5 min., further dilatation to $\frac{17}{50} \times \frac{17}{50}$; and in 1 hour 10 min., slight contraction to $\frac{15}{50} \times \frac{15}{50}$.—On the following day, the size was $\frac{16}{50} \times \frac{16}{50}$; and on the 4th day, $\frac{14}{50} \times \frac{13}{50}$.	*With atropia*, none noted. *After physostigma*, no accurate observation was possible.—On the following day, the rate per 10 sec. was 39; and on the 3d day, 40.	*With atropia*, none noted. *After physostigma*, none noted.	*With atropia*, none. *After physostigma*, in 13 min., the occurrence of moist laryngeal sounds with respiration indicated some increase of secretion, and these sounds occurred several times. There was no salivation nor defæcation; but in 1 hour a small quantity of urine was voided almost *guttatim*; and in 1 hour 10 min., in a copious stream.	*With atropia*, none. *After physostigma*, in 7 min., slight paralysis; in 20 min., very decided paralysis; and in 2 hours, slight paralysis. Tremors frequently occurred, and slight feeble spasms occasionally. Fibrillary twitches was present in a prominent form during at least 2 hours.
	b	3 lbs.	0	0	1·2	Death, in 27 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
127. *a* [Experiment *b* was performed eight days after experiment *a*.]	3 lbs. 6 oz.	0·1	0·088	3·4	Recovery.	*With atropia*, in 3 min. 30 sec., dilatation from $\frac{15}{60}\times\frac{15}{60}$ to $\frac{16}{60}\times\frac{16}{60}$. *After physostigma*, in 2 min., further dilatation to $\frac{18}{60}\times\frac{18}{60}$; and in 1 hour 20 min., contraction to $\frac{17}{60}\times\frac{17}{60}$.—On the 8th day the size was still $\frac{15}{60}\times\frac{15}{60}$.	*With atropia*, in 4 min. 30 sec., acceleration from 36 to 45 per 10 sec. *After physostigma*, in 1 hour, the rate per 10 sec. was 48; in 2 hours, 44; and in 2 hours 45 min., 48.—On the following day the rate per 10 sec. was 37.	*With atropia*, none. *After physostigma*, slowing from the original rate of 22 per 10 sec. took place; and in 2 min., the rate was 19, which in 1 hour, it was 12.	*With atropia*, none. *After physostigma*, none for at least 3 hours.	*With atropia*, none. *After physostigma*, in 10 min., slight paralysis; in 20 min., well-marked paralysis; and in 3 hours, decided though greatly diminished paralysis. Tremors frequently occurred, and fibrillary twitches were present in a well developed form.
b	3 lbs. 5 oz.	0	0	1·9 (= nearly 1·8 gr. p. 3 lbs.)	Death, in 16 min.	—	—	—	—	—
128. *a* [Experiment *b* was performed eight days after experiment *a*.]	3 lbs. 7 oz.	0·5	0·43	3·5	Recovery.	*With atropia*, in 4 min., dilatation from $\frac{14}{60}\times\frac{13}{60}$ to $\frac{16}{60}\times\frac{16}{60}$. *After physostigma*, in 4 min., further dilatation to $\frac{17}{60}\times\frac{17}{60}$. This size continued for 3 hours.—On the following day the size was $\frac{18}{60}\times\frac{18}{60}$; on the 4th day, $\frac{17}{60}\times\frac{17}{60}$; and on the 8th day, $\frac{14}{60}\times\frac{13}{60}$.	*With atropia*, in 4 min. 30 sec., acceleration from 39 to 48 per 10 sec. *After physostigma*, in 24 min., the rate per 10 sec. was 50; in 35 min., 48; and in 3 hours 10 min., 48.—On the following day it was 32; and on the 4th day, 40.	*With atropia*, none noted. *After physostigma*, none noted.	*With atropia*, none. *After physostigma*, none.	*With atropia*, none. *After physostigma*, in 10 min., slight weakness; in 40 min., pretty well-advanced paralysis; and in 2 hours 20 min., almost no paralysis. Spasms occurred in 2 hours 10 min., and were frequently repeated during the next hour and 30 min. Fibrillary twitches were pretty well-developed.
b	3 lbs. 8 oz.	0	0	1·7 (= about 1·5 gr. p. 3 lbs.)	Death, in 19 min.	—	—	—	—	—
129. *a* [Experiment *b* was performed six days after experiment *a*.]	3 lbs. 6 oz.	0·5	0·44	3·3	Recovery.	*With atropia*, in 2 min. 30 sec., dilatation from $\frac{15}{60}\times\frac{14}{60}$ to $\frac{17}{60}\times\frac{17}{60}$. *After physostigma*, the above size was maintained for 2 hours 50 min.—On the following day the size was $\frac{18}{60}\times\frac{18}{60}$; and on the 9th day, $\frac{16}{60}\times\frac{14}{60}$.	*With atropia*, in 4 min., acceleration from 37 to 45 per 10 sec. *After physostigma*, the rate could not be ascertained until 2 hours, when it was 46 per 10 sec.—On the following day it was 32 per 10 sec.	*With atropia*, none noted. *After physostigma*, slowing occurred. In 23 min. the rate per 10 sec. was 17; in 1 hour, 13; and in 1 hour 10 min., 12.	*With atropia*, in 3 min., several fæcal pellets were passed. *After physostigma*, none. Neither defæcation nor urination occurred, nor was the secretion of any gland increased.	*With atropia*, none. *After physostigma*, in 15 min., decided paralysis; in 1 hour, well-marked paralysis and general flaccidity; and in 2 hours, only very slight paralysis. Occasionally weak tremors occurred; and fibrillary twitches were but slightly developed.
b	3 lbs. 6 oz.	0	0	1·35 (= 1·2 gr. p. 3 lbs.)	Death, in 30 min.	—		—	—	—

Number of Experiment.		Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
130.	*a*	3 lbs. 6 oz. [Experiment *b* was performed nine days after experiment *a*.]	1·17	1·	3·4	Recovery.	*With atropia*, in 3 min., dilatation from $\frac{10}{50} \times \frac{9}{50}$ to $\frac{16}{50} \times \frac{15}{50}$. *After physostigma*, in 2 min. 30 sec., further dilatation to $\frac{16}{50} \times \frac{16}{50}$. Afterwards contraction occurred, in 1 hour 7 min., to $\frac{15}{50} \times \frac{16}{50}$; and in 2 hours, to $\frac{14}{50} \times \frac{14}{50}$.—On the following day the size was $\frac{14}{50} \times \frac{13}{50}$; and on the 4th day, $\frac{13}{50} \times \frac{12}{50}$.	*With atropia*, in 3 min. 20 sec., acceleration from 34 to 42 per 10 sec. *After physostigma*, in 1 hour 6 min., slowing had occurred to 28 per 10 sec. In 2 hours 25 min. the rate per 10 sec. was 37.—On the following day it was 30; and on the 3d day, 38 per 10 sec.	*With atropia*, none noted. *After physostigma*, slowing occurred, from the original rate per 10 sec. of 19 to, in 1 hour 7 min., 14; and this rate continued for more than 1 hour.	*With atropia*, none. *After physostigma*, none, until 1 hour 5 min., when laryngeal sounds showed that the secretion of certain buccal glands was increased. These sounds, however, continued for only 8 min. In 1 hour 15 min., normal fæcal pellets were passed; and in 2 hours, some wet fæcal.	*With atropia*, none. *After physostigma*, in 15 min., distinct paralysis; in 19 min., decided paralysis; and in 2 hours 30 min., pretty well-marked, though diminished, paralysis. Tremors occasionally occurred; and fibrillary twitches were well developed at an early period, but they had almost disappeared in 2 hours.
	b	3 lbs. 7 oz.	0	0	1·7 (= 1·5 gr. p. 3 lbs.	Death, in 16 min.	—	—	—	—	—
131.	*a*	3 lbs. 12 oz. [Experiment *b* was performed ten days after experiment *a*.]	1·5	1·2	3·7	Recovery.	*With atropia*, in 4 min., dilatation from $\frac{16}{50} \times \frac{14}{50}$ to $\frac{18}{50} \times \frac{18}{50}$. *After physostigma*, in 31 min., the size was $\frac{18}{50} \times \frac{18}{50}$; in 2 hours 10 min., $\frac{17}{50} \times \frac{17}{50}$; and in 4 hours, $\frac{17}{50} \times \frac{17}{50}$.—On the following day it was $\frac{20}{50} \times \frac{20}{50}$; and on the 11th day, $\frac{14}{50} \times \frac{13}{50}$.	*With atropia*, in 3 min. 50 sec., acceleration from 36 to 47 per 10 sec. *After physostigma*, in 4 min., the rate per 10 sec. was 48; in 19 min., 54; in 1 hour, 52; in 2 hours 20 min., 50; in 2 hours 50 min., 45; and in 4 hours, 50.—On the following day the rate per 10 sec. was 32.	*With atropia*, none noted. *After physostigma*, slowing occurred. In 31 min., the rate per 10 sec. was 17; in 41 min., 11; and in 2 hours, 12.	*With atropia*, none. *After physostigma*, none, until 3 hours 11 min., when slight mucous sounds accompanied the respirations during 10 min. or so. Neither defæcation nor urination occurred.	*With atropia*, none. *After physostigma*, in 13 min., slight paralysis; in 31 min., decided paralysis and some flaccidity; and in 4 hours, only slight weakness. Well-marked tremors frequently occurred. Fibrillary twitches were present in a slight form for about 1 hour, they then almost disappeared, but again became prominent in 2 hours 30 min.
	b	3 lbs. 13 oz.	0	0	1·5 (= 1·2 gr. p. 3 lbs.)	Death, in 34 min.	—	—	—	—	—
132.	*a*	4 lbs. 1 oz. [Experiment *b* was performed eight days after experiment *a*.]	1·7	1·25	4·1	Recovery.	*With atropia*, in 4 min., dilatation from $\frac{13}{50} \times \frac{12}{50}$ to $\frac{16}{50} \times \frac{16}{50}$. *After physostigma*, the size remained about $\frac{16}{50} \times \frac{16}{50}$ for more than 2 hours.—On the following day the size was $\frac{18}{50} \times \frac{18}{50}$; and on the 4th day, $\frac{16}{50} \times \frac{16}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 41 to 50 per 10 sec. *After physostigma*, in 27 min., the rate per 10 sec. was 55.—On the following day it was 36; and on the 4th day, 40.	*With atropia*, none noted. *After physostigma*, considerable slowing took place.	*With atropia*, none. *After physostigma*, in 16 min., urine was freely voided. Neither defæcation occurred, nor was the secretion of any gland increased during the 2 hours of continuous observation.	*With atropia*, none. *After physostigma*, in 12 min., slight weakness; in 20 min., decided paralysis; and in 2 hours, pretty distinct paralysis. No tremors occurred, but several spasms, having an emprosthotonic character, appeared after 1 hour and 25 min. Fibrillary twitches were only slightly developed, and at the earlier part of the experiment.
	b	4 lbs. 2 oz.	0	0	1·65 (= 1·2 gr. p. 3 lbs.)	Death, in 28 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
133. *a* [Experiment *b* was performed ten days after experiment *a*.]	3 lbs. 2 oz.	1·7	1·63	3·4	Recovery.	*With atropia*, in 4 min., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{16}{50} \times \frac{16}{50}$. *After physostigma*, in 1 hour, the size had become $\frac{18}{50} \times \frac{18}{50}$.	*With atropia*, in 4 min. 20 sec., acceleration from 38 to 49 per 10 sec. *After physostigma*, in 5 min., the rate per 10 sec. was 52; in 20 min., it was 57; in 1 hour, 54; and in 3 hours 30 min., 45.	*With atropia*, none. *After physostigma*, slowing occurred from the original rate per 10 sec. of 16 to, in 30 min., 14; in 1 hour, 13; and in 3 hours 30 min., also 13. A slightly accelerated rate, however, preceded this slowing.	*With atropia*, none. *After physostigma*, none. Neither defæcation nor urination occurred, nor was there any evidence of increase in the secretion of the buccal or other glands during the 3 hours and 30 min. of continuous observation.	*With atropia*, none. *After physostigma*, in 11 min., slight weakness of anterior extremities; in 18 min., well-marked general paralysis and flaccidity; and in 3 hours 30 min., only a little weakness. Feeble tremors and spasms occasionally occurred; and fibrillary twitches were present in a slight form.
b	3 lbs. 2 oz.	0	0	1·25 (= 1·2 gr. p. 3 lbs.)	Death, in 26 min.	—	—	—	—	—
134. *a* [Experiment *b* was Performed ten days after experiment *a*.]	3 lbs.	2·	2·	3·	Recovery.	*With atropia*, in 3 min., dilatation from $\frac{11}{50} \times \frac{10}{50}$ to $\frac{16}{50} \times \frac{15}{50}$. *After physostigma*, in 2 min., further dilatation to $\frac{16}{50} \times \frac{16}{50}$; and in 8 min., to $\frac{17}{50} \times \frac{17}{50}$. Contraction afterwards occurred, and in 1 hour 15 min., the size was $\frac{14}{50} \times \frac{14}{50}$.—On the following day, it was $\frac{17}{50} \times \frac{17}{50}$; and on the 4th day, $\frac{13}{50} \times \frac{13}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 40 to 53 per 10 sec. *After physostigma*, no observations were made until the following day, when the rate per 10 sec. was 40; but the impulse was weak.	*With atropia*, none noted. *After physostigma*, slowing occurred. In 1 hour 30 min., the rate per 10 sec. was 16; in 1 hour 47 min., 12; in 1 hour 55 min., 10; in 2 hours, 9; and in 2 hours 10 min., 13.	*With atropia*, none. *After physostigma*, in 1 hour 15 min., several normal fæcal pellets were passed; and in 1 hour 22 min., urine was freely voided. No increase occurred in the secretion of any buccal gland.	*With atropia*, none. *After physostigma*, in 11 min., slight weakness; in 20 min., decided paralysis, soon followed by general flaccidity; and in 1 hour 30 min., only very slight weakness. Feeble tremors occurred occasionally, and fibrillary twitches were present during the earlier part of the experiment.
b	3 lbs. ½ oz.	0	0	1·2	Death, in 22 min.	—	—	—	—	—
135.	3 lbs.	2·	2·	3·	Death, in 52 min. after the administration of physostigma.	*With atropia*, in 3 min. 30 sec., dilatation from $\frac{11}{50} \times \frac{10}{50}$ to $\frac{15}{50} \times \frac{15}{50}$. *After physostigma*, in 1 min. 30 sec., further dilatation to $\frac{16}{50} \times \frac{16}{50}$; and this size continued until death. — After death, in 8 min., the size was $\frac{12}{50} \times \frac{12}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 39 to 50 per 10 sec. *After physostigma*, in 4 min., further acceleration to 58 per 10 sec.; then slowing, in 18 min., to 40 per 10 sec., which rate was continued until 46 min.; and afterwards gradual slowing until death, the rate per 10 sec. being in 49 min., 34, and in 51 min., 15.	*With atropia*, none. *After physostigma*, slight acceleration followed by slowing. The rate per 10 sec. was in 34 min., 16; in 37 min., 14; in 42 min., 12; in 44 min., 6; in 48 min., 4; and afterwards only rare gasps occurred until death.	*With atropia*, none. *After physostigma*, none.	*With atropia*, none. *After physostigma*, in 11 min., distinct paralysis; in 20 min., very decided paralysis; and in 26 min., general flaccidity. Very feeble tremors occasionally occurred, and fibrillary twitches were but slightly developed.

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
136.* [Experiment *b* was performed fourteen days after experiment *a*.—The animal was a common wild rabbit.]										
a	3 lbs.	2·2	2·2	3	Recovery.	*With atropia*, dilatation occurred. *After physostigma*, dilatation remained for more than 2 hours 30 min.	*With atropia*, acceleration took place. *After physostigma*, further acceleration took place, and then slight slowing. In 32 min., the rate per 10 sec. was 52; and in 2 hours 30 min., 49. The impulse was weaker at the latter than at the former time.	*With atropia*, none noted. *After physostigma*, slight acceleration followed by slowing. In 32 min., the rate per 10 sec. was 24; in 41 min., 15; and in 2 hours 30 min., 11.	*With atropia*, none. *After physostigma*, none.	*With atropia*, none. *After physostigma*, in 11 min., decided paralysis; in 32 min., considerable general flaccidity; and in 2 hours 30 min., distinct though less complete paralysis. Rarely some feeble tremors occurred. Fibrillary twitches were only slightly developed.
b	3 lbs. 1 oz.	0	0	3	Death, in 12 min.	—	—	—	—	—
137.	2 lbs. 15½ oz.	2·27	2·3	2·93	Death, in 31 min. after the administration of physostigma.	*With atropia*, in 3 min., dilatation from $\frac{13}{50} \times \frac{12}{50}$ to $\frac{15}{50} \times \frac{15}{50}$. *After physostigma*, in 3 min., further dilatation to $\frac{17}{50} \times \frac{17}{50}$; in 9 min., slight contraction to $\frac{16}{50} \times \frac{16}{50}$; and the latter size was maintained until death.—After death the size was in 1 min., $\frac{16}{50} \times \frac{16}{50}$; in 4 min., $\frac{14}{50} \times \frac{14}{50}$; in 16 min., $\frac{12}{50} \times \frac{12}{50}$; and in 25 min., $\frac{9}{50} \times \frac{9}{50}$.	*With atropia*, in 4 min., acceleration from 35 to 47 per 10 sec. *After physostigma*, the rate was not counted.	*With atropia*, in 4 min. 20 sec., acceleration from 9 to 13 per 10 sec.. *After physostigma*, further acceleration occurred, and then slowing until death.	*With atropia*, none. *After physostigma*, none.	*With atropia*, none. *After physostigma*, in 6 min., slight paralysis; in 22 min., decided paralysis; and in 30 min., general flaccidity, accompanied with occasional tremors and even feeble general spasms. Fibrillary twitches were pretty well developed.
138.	3 lbs.	2·6	2·6	3	Death, in 18 min. after the administration of physostigma.	*With atropia*, in 4 min. 30 sec., dilatation from $\frac{14}{50} \times \frac{14}{50}$ to $\frac{18}{50} \times \frac{18}{50}$. *After physostigma*, in 13 min., further dilatation to $\frac{19}{50} \times \frac{19}{50}$; and in 17 min., to $\frac{20}{50} \times \frac{20}{50}$.—At death, the size was $\frac{20}{50} \times \frac{20}{50}$; and 3 min. afterwards it was $\frac{11}{50} \times \frac{11}{50}$.	*With atropia*, in 3 min. 30 sec., acceleration from 40 to 56 per 10 sec. *After physostigma*, in 11 min., further acceleration to 60 per 10 sec. Gradual slowing then occurred; and at 1 min. before death the rate per 10 sec. was 22.	*With atropia*, none. *After physostigma*, the rate per 10 sec. was in 5 min., 20; in 8 min., 19; in 13 min., 10; and 1 min. before death, only 2 gasps occurred per 30 sec.	*With atropia*, none. *After physostigma*, in 12 min., a few drops of urine were voided. No other effect was produced.	*With atropia*, none. *After physostigma*, in 9 min., decided paralysis; and in 13 min., general flaccidity, accompanied with feeble tremors and spasms. Fibrillary twitches were pretty well developed.—The first appearance of rigor was at 1 hour and 10 min. after death (temp. of laboratory, 56° F.).
139.	3 lbs. 6 oz.	3	2·66	3·4	Death, in 33 min. after the administration of physostigma.	*With atropia*, in 4 min., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{15}{50} \times \frac{16}{50}$. *After physostigma*, in 3 min., further dilatation to $\frac{16}{50} \times \frac{16}{50}$, which size remained until death.—After death, the size was in 3 min., $\frac{14}{50} \times \frac{13}{50}$; in 17 min., $\frac{11}{50} \times \frac{10}{50}$; and in 40 min., $\frac{10}{50} \times \frac{9}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 38 to 47 per 10 sec. *After physostigma*, the rate per 10 sec. was in 15 min., 53; and in 28 min., 31.	*With atropia*, none. *After physostigma*, the rate per 10 sec., was in 14 min, 13; in 17 min., 12; in 20 min., 8; and in 23 min., only feeble gasps occurred very infrequently.	*With atropia*, none. *After physostigma*, none.	*With atropia*, none. *After physostigma*, in 9 min., decided paralysis; and in 15 min., general flaccidity. Several feeble tremors occurred shortly before death. Fibrillary twitches were but slightly developed.—There was no appearance of rigor at 2 hours 30 min. after death (temp. of laboratory, 56° F.).

* This animal was a common wild rabbit.

TABLE 6.—EXPERIMENTS WITH THREE TIMES THE MINIMUM-LETHAL DOSE OF PHYSOSTIGMA (3·6 *grs. of Extract of Physostigma per Three Pounds Weight of Rabbit*).

Number of Experiment.	Weight of Rabbit	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal	Dose of Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
140.	3 lbs. 7 oz.	0·05	0·043	4·1	Death, in 35 min. after the administration of physostigma.	*With atropia*, in 4 min., dilatation from $\frac{11}{50} \times \frac{10}{50}$ to $\frac{14}{50} \times \frac{14}{50}$. *After physostigma*, in 2 min., further dilatation to $\frac{16}{50} \times \frac{16}{50}$; and in 10 min., to $\frac{18}{50} \times \frac{18}{50}$. Contraction then occurred, in 25 min. to $\frac{9}{50} \times \frac{8}{50}$; and afterwards there was slight dilatation.	*With atropia*, in 3 min. 30 sec., acceleration from 39 to 51 per 10 sec. *After physostigma*, further acceleration took place, and in 2 min. 30 sec., the rate per 10 sec. was 56. Slight slowing afterwards occurred, and in 26 min., the rate per 10 sec. was 48.	*With atropia*, none noted. *After physostigma*, acceleration from the original rate per 10 sec. of 17 took place, and in 3 min. the rate was 24. Slowing afterwards set in. In 25 min. the rate per 10 sec. was 7; and in 30 min., only infrequent and feeble gasps occurred until death.	*With atropia*, none. *After physostigma*, in 21 min., several normal fæcal pellets were passed. No urination occurred; and a slight and only temporary increase took place in the secretion of certain buccal glands, shown by movements of the lips soon after physostigma was injected.	*With atropia*, none. *With physostigma*, in 7 min., decided paralysis; and in 20 min., general flaccidity, which continued, accompanied with gentle tremors, until death. Fibrillary twitches were pretty well developed.
141.	3 lbs.	0·05	0·05	3·6	Death, in 53 min. after the administration of physostigma.	*With atropia*, in 4 min., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{17}{50} \times \frac{17}{50}$. *After physostigma*, in 4 min., further dilatation to $\frac{18}{50} \times \frac{18}{50}$, and this size remained until death.—After death, in 3 min., the size was $\frac{15}{50} \times \frac{14}{50}$.	*With atropia*, in 3 min. 30 sec., acceleration from 40 to 51 per 10 sec. *After physostigma*, the acceleration was maintained until 22 min. In 34 min., the rate per 10 sec. was 28.	*With atropia*, none noted. *After physostigma*, slight acceleration occurred, and was followed by slowing. In 20 min., the rate per 10 sec. was 11; in 33 min., 7; and afterwards only infrequent and irregular gasps occurred until death.	*With atropia*, none. *After physostigma*, no increase of any secretion or excretion occurred.	*With atropia*, none. *After physostigma*, in 7 min., slight paralysis; and in 10 min., general flaccidity, which continued, accompanied with feeble tremors, until death. Fibrillary twitches were well developed.
142. *a* [Experiment *b* was performed eleven days after experiment *a*.]	3 lbs.	0·06	0·06	3·6	Recovery.	*With atropia*, in 4 min., dilatation from $\frac{14}{50} \times \frac{15}{50}$ to $\frac{15}{50} \times \frac{15}{50}$. *After physostigma*, the size was, in 6 min., $\frac{17}{50} \times \frac{17}{50}$; and in 2 hours 30 min., $\frac{18}{50} \times \frac{18}{50}$.—On the following day it was $\frac{15}{50} \times \frac{15}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 36 to 45 per 10 sec. *After physostigma*, this rate per 10 sec. was, in 5 min., 34; in 22 min., 41; in 1 hour 15 min., 36; and in 2 hours 35 min., 32.—On the following day it was 29.	*With atropia*, none. The original rate was 17 per 10 sec. *After physostigma*, the rate per 10 sec. was, in 7 min., 15; in 22 min., 16; in 1 hour 16 min., 13; and in 2 hours 31 min., 19.—On the following day it was 13.	*With atropia*, none. *After physostigma*, in 7 min., slight increase in the secretion of certain buccal glands, which soon ceased. In 3 hours 3 min., urine was voided. There was no defæcation nor salivation during the 3 hours and 15 min. of continuous observation.	*With atropia*, none. *After physostigma*, in 2 min., infrequent fibrillary twitches, which soon became very well marked, and continued so for more than 3 hours. In 12 min., slight paralysis; in 25 min., very decided paralysis; and in 2 hours 30 min., only slight paralysis. Occasionally tremors occurred.
b	3 lbs. 1 oz.	0	0	1·2	Death, in 20 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	phate of Atropia (in Grains). Actual Dose.	phate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
143. *a*	2 lbs. 15 oz. [Experiment *b* was performed nine days after experiment *a*.]	0·075	0·076	3·52	Recovery.	*With atropia*, in 3 min., dilatation from $\frac{11}{50} \times \frac{10}{50}$ to $\frac{14}{50} \times \frac{14}{50}$. *After physostigma*, in 43 min., further dilatation to $\frac{16}{50} \times \frac{16}{50}$.—On the following day, the size was $\frac{12}{50} \times \frac{11}{50}$.	*With atropia*, in 2 min. 30 sec., acceleration from 37 to 50 per 10 sec. *After physostigma*, in 43 min., the rate per 10 sec. was 52; and in 1 hour 40 min., 48.—On the following day, the rate per 10 sec. was 40.	*With atropia*, none noted. *After physostigma*, slowing took place from the original rate per 10 sec. of 28, to, in 43 min., 21; and no further slowing had occurred within 1 hour 50 min.	*With atropia*, none. *After physostigma*, none.	*With atropia*, none. *After physostigma*, in 8 min., slight paralysis; and in 53 min., well-marked paralysis: but flaccidity did not set in. Fibrillary twitches were well developed.
b	2 lbs. 15 oz.	0	0	1·17 (= 1·2 gr. p. 3 lbs.)	Death, in 24 min. 30 sec.	—	—	—	—	—
144. *a*	3 lbs. 5¾ oz. [Experiment *b* was performed seven days after experiment *a*.]	0·1	0·088	4·	Recovery.	*With atropia*, in 3 min. 30 sec., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{17}{50} \times \frac{17}{50}$. *After physostigma*, in 1 hour, contraction had occurred to $\frac{14}{50} \times \frac{14}{50}$, and this size continued until after 1 hour 30 min.—On the following day, the size was $\frac{17}{50} \times \frac{17}{50}$; and on the 3d day $\frac{16}{50} \times \frac{16}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 42 to 60 per 10 sec. *After physostigma*, the rate per 10 sec. was, in 45 min., 57; in 1 hour, 34; and in 1 hour 30 min., 29.—On the following day, the rate per 10 sec. was 52; and on the 3d day, 45.	*With atropia*, none noted. *After physostigma*, the rate per 10 sec. was, in 34 min., 16; in 1 hour, 12; and in 1 hour 25 min., 13.	*With atropia*, none. *After physostigma*, in 1 hour, slight salivation occurred, and continued for about 16 min. In 1 hour 20 min., several normal fæcal pellets were found. No urination occurred all this time.	*With atropia*, none. *After physostigma*, in 5 min., slight paralysis; in 25 min., general flaccidity; and in 1 hour 30 min., well-marked, though greatly diminished paralysis. Tremors frequently occurred, and several times there were weak spasms of an emprosthotonic character. Fibrillary twitches were pretty well developed, but only during the earlier part of the experiment.
b	3 lbs. 4 oz.	0	0	1·3 (= 1·2 gr. p. 3 lbs.)	Death, in 28 min.	—	—	—	—	—
42.* *a*	3 lbs. 4 oz. [Experiment *b* was performed eight days after experiment *a*.]	0·17	0·16	3·9	Recovery.	*With atropia*, in 4 min., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{16}{50} \times \frac{16}{50}$. *After physostigma*, in 3 min. 10 sec., further dilatation to $\frac{18}{50} \times \frac{18}{50}$; then, in 2 hours 30 sec., slight contraction to $\frac{17}{50} \times \frac{17}{50}$.—On the following day, the size was $\frac{17}{50} \times \frac{17}{50}$; and on the 5th day, $\frac{14}{50} \times \frac{13}{50}$.	*With atropia*, in 4 min. 10 sec., acceleration from 42 to 54 per 10 sec. *After physostigma*, the rate per 10 sec. was, in 5 min., 60; in 40 min., 57; in 2 hours 30 sec., 47; and in 6 hours 30 min., 31.—On the following day, the rate per 10 sec. was 27; and on the 5th day, 40.	*With atropia*, in 4 min. 30 sec., slowing from 26 to 18 per 10 sec. *After physostigma*, the rate per 10 sec. was, in 15 min., 19; in 40 min., 13; in 50 min., 11; in 2 hours, 12; and in 6 hours 30 min., about 24.	*With atropia*, none. *After physostigma*, in 6 hours 30 min., normal fæcal pellets were passed; but no urine had been voided, nor had any increase occurred in the secretion of the buccal glands.	*With atropia*, none. *After physostigma*, in 10 min., slight weakness; in 15 min., decided paralysis; and in 6 hours 30 min., almost no paralysis. Slight tremors occurred; and fibrillary twitches were well developed during the earlier part of the experiment.
b	3 lbs. 5 oz.	0	0	1·3	Death in 31 min.	—	—	—	—	—

* A full description of this experiment has already been given in Section A (see p. 546).

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
145. *a*	3 lbs. [Experiment *b* was performed fifteen days after experiment *a*.]	0·5	0·5	3·6	Recovery.	*With atropia*, in 4 min., dilatation from $\frac{12}{60} \times \frac{11}{60}$ to $\frac{15}{60} \times \frac{15}{60}$. *After physostigma*, in 23 min., further dilatation to $\frac{18}{60} \times \frac{18}{60}$; then, in 1 hour, contraction to $\frac{17}{60} \times \frac{17}{60}$; and in 2 hours, to $\frac{16}{60} \times \frac{16}{60}$.—On the following day, the size was $\frac{18}{60} \times \frac{18}{60}$; on the 3d day, $\frac{19}{60} \times \frac{19}{60}$; and on the 16th day, $\frac{14}{60} \times \frac{13}{60}$.	*With atropia*, in 3 min. 30 sec., acceleration from 41 to 56 per 10 sec. *After physostigma*, the rate per 10 sec. was, in 7 min., 61; in 21 min., 56; and in 2 hours, 56.—On the following day, it was 38; and on the 3d day, 34.	*With atropia*, in 4 min. 30 sec., acceleration from 22 to 26 per 10 sec. *After physostigma*, the rate per 10 sec. was, in 41 min., 21; in 1 hour, 21; and in 2 hours, 19.	*With atropia*, none. *After physostigma*, none. Neither defæcation nor urination occurred, nor was the secretion of any buccal gland increased during the 3 hours of continuous observation.	*With atropia*, none. *After physostigma*, in 10 min., decided paralysis; in 22 min., general flaccidity; and in 2 hours, only a little weakness. Tremors and very weak spasms frequently occurred, until 2 hours; but fibrillary twitches continued in a well-marked form for more than 3 hours.
b	3 lbs.	0	0	1·2	Death in 27 min.	—	—	—	—	—
146. *a*	3 lbs. [Experiment *b* was performed forty-one days after experiment *a*; and this rabbit was also used, twenty-one days after experiment 146 *a*, in experiment 108 *a*.]	1	1	3·6	Recovery.	*With atropia*, in 3 min. 30 sec., dilatation from $\frac{14}{60} \times \frac{13}{60}$ to $\frac{17}{60} \times \frac{17}{60}$. *After physostigma*, in 2 min., further dilatation to $\frac{18}{60} \times \frac{18}{60}$. No obvious contraction took place for at least 1 hour 40 min.—On the following day, the size was $\frac{18}{60} \times \frac{18}{60}$.	*With atropia*, in 4 min., acceleration from 39 to 51 per 10 sec. *After physostigma*, the rate per 10 sec. was, in 3 min., 52; in 12 min., 57; in 50 min., 56; in 58 min., 46; in 1 hour 3 min., 39; and in 1 hour 40 min., 38.—On the following day, the rate per 10 sec. was 29.	*With atropia*, in 3 min., slowing from 32 to 25 per 10 sec. *After physostigma*, the rate per 10 sec. was, in 3 min. 30 sec., 27; in 50 min., 18; in 1 hour 2 min., 12; and in 2 hours, 11.	*With atropia*, none. *After physostigma*, none. Neither defæcation nor urination occurred, nor was the secretion of any buccal gland increased during the 2 hours of continuous observation.	*With atropia*, none. *After physostigma*, in 9 min., distinct paralysis; and in 30 min., general flaccidity, which was still present in 2 hours. Gentle tremors occasionally took place, and fibrillary twitches were slightly developed, but they occurred only at the earlier part of the experiment.
b	3 lbs.	0	0	1·2	Death, in 14 min.	—	—	—	—	—
147. *a*	3 lbs. [Experiment *b* was performed nine days after experiment *a*.]	1·2	1·2	3·6	Recovery.	*With atropia*, in 2 min. 30 sec., dilatation from $\frac{13}{50} \times \frac{13}{50}$ to $\frac{15}{50} \times \frac{15}{50}$. *After physostigma*, in 2 min., further dilatation to $\frac{18}{50} \times \frac{18}{50}$; and in 1 hour 30 min., contraction to $\frac{14}{50} \times \frac{14}{50}$, which size remained until after 2 hours 40 min.—On the following day, the size was $\frac{14}{50} \times \frac{14}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 36 to 52 per 10 sec. *After physostigma*, the rate per 10 sec. was, in 3 min., 56; and in 1 hour 12 min., 36.—On the following day, the rate per 10 sec. was 35.	*With atropia*, in 3 min., slowing from 19 to 15 per 10 sec. *After physostigma*, the rate per 10 sec. was, in 22 min., 14; and in 40 min., 13.	*With atropia*, none. *After physostigma*, in 18 min., urine was freely voided; and in 1 hour 10 min., several normal fæcal pellets were passed. No increase occurred in the secretion of any buccal gland, until 1 hour 25 min., when a very little salivation occurred.	*With atropia*, none. *After physostigma*, in 10 min., slight paralysis; in 30 min., general flaccidity; and in 2 hours 20 min., slight paralysis. Tremors now and then occurred. Fibrillary twitches were present in a pretty well-marked form until at least 2 hours 20 min.
b	3 lbs. 2 oz.	0	0	1·25 (= 1·2 gr. p. 3 lbs.)	Death, in 25 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Sulphate of Atropia (in Grains). Actual Dose.	Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
148.	3 lbs.	1·3	1·3	3·6	Death, in 1 hour 13 min., after the administration of physostigma.	*With atropia*, in 3 min., dilatation from $\frac{11}{50} \times \frac{10}{50}$ to $\frac{17}{50} \times \frac{17}{50}$. *After physostigma*, the size was in 2 min. $\frac{17}{50} \times \frac{17}{50}$; in 31 min., $\frac{16}{50} \times \frac{16}{50}$; in 48 min., $\frac{12}{50} \times \frac{12}{50}$; and in 1 hour 6 min., $\frac{14}{50} \times \frac{14}{50}$.—After death, the size was in 1 min. $\frac{11}{50} \times \frac{10}{50}$.	*With atropia*, in 4 min., acceleration from 45 to 54 per 10 sec. *After physostigma*, the rate per 10 sec. was, in 20 min., 60; in 35 min., 58; and in 45 min., 48.	*With atropia*, none. *After physostigma*, the rate per 10 sec. was, in 10 min., 22; in 15 min., 17; in 45 min., 9; and in 58 min., 4. Afterwards, rare gasps occurred irregularly until death.	*With atropia*, none. *After physostigma*, none. During the experiment, neither defæcation nor urination occurred, nor was the secretion of any buccal gland increased.	*With atropia*, none. *After physostigma*, in 6 min., distinct paralysis; and in 10 min., general flaccidity, which continued until death. Tremors and weak spasms frequently occurred. Fibrillary twitches were well marked during the first 28 min., but they afterwards diminished, and had almost disappeared before death. The first appearance of rigor mortis was seen at 1 hour and 25 min. after death (temp. of laboratory, 62° F.).
149.	3 lbs. 6 oz.	1·55	1·4	4·05	Death, in 49 min. after the administration of physostigma.	*With atropia*, in 4 min. 30 sec., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{18}{50} \times \frac{18}{50}$. *After physostigma*, the size was in 45 min., $\frac{14}{50} \times \frac{14}{50}$.	*With atropia*, in 4 min., acceleration from 37 to 54 per 10 sec. *After physostigma*, no observation could be made until 13 min., when the rate per 10 sec. was about 40; and in 44 min., it was 22.	*With atropia*, none noted. *After physostigma*, the respirations were rapid until 20 min., and they then diminished in frequency. In 33 min., the rate per 10 sec. was only 6; and afterwards gasps occurred at rare intervals until death.	*With atropia*, none. *After physostigma*, neither defæcation nor urination occurred, nor was the secretion of any buccal gland increased.	*With atropia*, none. *After physostigma*, in 9 min., slight paralysis; and in 25 min., general flaccidity. Tremors and weak spasms frequently occurred. Fibrillary twitches were present in a well-marked form until 18 min. after the injection of physostigma, but soon afterwards they disappeared. There was no rigor within 48 min. after death (temp. of laboratory, 58° F.).
150.	3 lbs. 2 oz.	2	1·9	3·7	Death, in 21 min. after the administration of physostigma.	*With atropia*, none noted. *After physostigma*, none noted.	*With atropia*, none noted. *After physostigma*, none noted.	*With atropia*, none. *After physostigma*, slowing occurred, and in 19 min. the rate per 10 sec. was 11.	*With atropia*, none. *After physostigma*, none. Neither defæcation nor urination occurred; nor was the secretion of any buccal gland increased.	*With atropia*, none. *After physostigma*, in 13 min., slight paralysis; and in 17 min., flaccidity. Tremors and spasms frequently occurred, and fibrillary twitches were present in a well-marked form.

TABLE 7.—EXPERIMENTS WITH THREE AND A HALF TIMES THE MINIMUM-LETHAL DOSE OF PHYSOSTIGMA (4·2 *grs. of Extract of Physostigma per Three Pounds Weight of Rabbit*).

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
151.	3 lbs. 6 oz.	0·05	0·044	4·7	Death, in 1 hour 18 min. after the administration of physostigma.	*With atropia*, in 3 min., dilatation from $\frac{15}{50} \times \frac{14}{50}$ to $\frac{17}{50} \times \frac{17}{50}$. *After physostigma*, in 4 min., the size was $\frac{17}{50} \times \frac{17}{50}$; afterwards slight contraction occurred; but in 1 hour, the size was again $\frac{17}{50} \times \frac{17}{50}$, and continued so until death.	*With atropia*, in 4 min., acceleration from 39 to 48 per 10 sec. *After physostigma*, in 4 min., the rate per 10 sec. was 49. After this, no observation was made until 1 hour 7 min., when the rate per 10 sec. was 35. Afterwards it rapidly slowed.	*With atropia*, none. *After physostigma*, in 17 min., slowing had occurred from the original rate of 21 per 10 sec. to 18. In 25 min., the rate per 10 sec. was 15; in 35 min., 13; in 52 min., 9; in 1 hour, 5; and afterwards irregular gasps occurred until death.	*With atropia*, none. *After physostigma*, none. Neither defæcation nor urination occurred, nor was the secretion of any buccal gland increased.	*With atropia*, none. *After physostigma*, in 7 min., slight paralysis; and in 48 min., general flaccidity. Tremors and spasms frequently occurred, and fibrillary twitches were well developed.
152.	2 lbs. 13 oz.	0·075	0·071	3·9	Death, in 21 min. after the administration of physostigma.	*With atropia*, in 4 min., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{14}{50} \times \frac{14}{50}$. *After physostigma*, the size was in 5 min., $\frac{15}{50} \times \frac{15}{50}$; and in 21 min., $\frac{10}{50} \times \frac{9}{50}$.—After death in 7 min., the size was $\frac{9}{50} \times \frac{8}{50}$.	*With atropia*, in 3 min., acceleration from 41 to 47 per 10 sec. *After physostigma*, in 5 min., the rate per 10 sec. was 48. Further observations were not made until 20 min., when the rate per 10 sec. was 13.	*With atropia*, none. *After physostigma*, the rate soon diminished, and in 14 min. infrequent gasps merely were occurring.	*With atropia*, none. *After physostigma*, none.	*With atropia*, none. *After physostigma*, in 7 min., slight paralysis; and in 13 min., general flaccidity. Very feeble tremors occurred, though only at about 10 min. after the administration of physostigma. Fibrillary twitches were well developed, and continued after death.
153.	2 lbs. 15 oz.	0·1	0·1	4·1	Recovery.	*With atropia*, in 4 min. 30 sec., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{15}{50} \times \frac{15}{50}$. *After physostigma*, the size remained $\frac{15}{50} \times \frac{15}{50}$ for more than 2 hours. —On the following day, it was $\frac{15}{50} \times \frac{15}{50}$; and on the 3d day, $\frac{11}{50} \times \frac{10}{50}$.	*With atropia*, in 3 min., acceleration from 37 to 44 per 10 sec. *After physostigma*, no observations were made until 1 hour 50 min., when the rate per 10 sec. was 45.—On the following day, it was 27; and on the 3d day, 41.	*With atropia*, in 4 min., slowing from 18 to 16 per 10 sec. *After physostigma*, the rate per 10 sec. was in 33 min., 18; in 1 hour, 14; and in 2 hours, 15.	*With atropia*, none. *After physostigma*, in 22 min., several normal fæcal pellets were passed; and also in 38 min., with a few drops of urine. No salivation occurred, nor was the secretion of any buccal gland increased.	*With atropia*, none. *After physostigma*, in 7 min., slight paralysis; in 33 min., advanced paralysis; in 1 hour 6 min., general flaccidity; and in 2 hours, decided, though lessened paralysis. Tremors early occurred, and were frequently repeated. Fibrillary twitches were present in a very well-marked form until 2 hours 10 min. at least.*

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
154. *a* [Experiment *b* was performed nine days after experiment *a*.]	3 lbs.	0·2	0·2	4·2	Recovery.	*With atropia*, in 4 min., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{17}{50} \times \frac{17}{50}$. *After physostigma*, the size continued $\frac{17}{50} \times \frac{17}{50}$ for at least 3 hours.—On the following day, it was still $\frac{17}{50} \times \frac{17}{50}$; on the 4th day, it was $\frac{16}{50} \times \frac{16}{50}$; and on the 9th day, $\frac{14}{50} \times \frac{13}{50}$.	*With atropia*, in 4 min. 20 sec., acceleration from 39 to 50 per 10 sec. *After physostigma*, the rate per 10 sec. was in 3 min., 58; and in 1 hour 55 min., 48.—On the following day, the rate per 10 sec. was 45.	*With atropia*, in 3 min., acceleration from 18 to 22 per 10 sec. *After physostigma*, the rate per 10 sec. was in 23 min., 19; in 39 min., 17; in 50 min., 14; and in 2 hours, 15.	*With atropia*, none. *After physostigma*, none. Neither defæcation nor urination occurred, nor was the secretion of any buccal gland increased.	*With atropia*, none. *After physostigma*, in 7 min., slight paralysis; and in 18 min., general flaccidity. The paralysis began to lessen in about 1 hour 10 min.; and in 2 hours 30 min., was only slight. Tremors and feeble starts occurred frequently, and fibrillary twitches were very well marked, even at 3 hours.
	2lbs.15¾oz.	0	0	1·2 (= nearly 1·2 gr. per3lbs.)	Death, in 12 min. 30 sec.	—	—	—	—	—
155.	3 lbs.	0·3	0·3	4·2	Death, in 45 min. after the administration of physostigma.	*With atropia*, in 3 min., dilatation from $\frac{11}{50} \times \frac{10}{50}$ to $\frac{14}{50} \times \frac{14}{50}$. *After physostigma*, the size was in 2 min., $\frac{15}{50} \times \frac{16}{50}$; in 12 min., $\frac{14}{50} \times \frac{14}{50}$; in 20 min., $\frac{9}{50} \times \frac{8}{50}$; in 35 min., $\frac{5}{50} \times \frac{4}{50}$; and in 45 min., $\frac{5}{50} \times \frac{4}{50}$. —After death, in 3 min., the size was $\frac{11}{50} \times \frac{11}{50}$; and in 35 min., $\frac{7}{50} \times \frac{6}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 44 to 53 per 10 sec. *After physostigma*, no observations were made in order to avoid interference with the result of the experiment.	*With atropia*, none noted. *After physostigma*, the respirations slowed until death. In 38 min., moist sounds occurred now and then, and they continued to do so until death.	*With atropia*, none. *After physostigma*, neither defæcation nor urination occurred; but the secretion of certain buccal or laryngeal glands was a little increased.	*With atropia*, none. *After physostigma*, in 8 min., decided paralysis; and in 20 min., general flaccidity, which remained until death. Tremors frequently occurred, and fibrillary twitches were present in a very well-marked form. — After death, in 35 min., only a faint degree of rigor was present in the posterior extremities (temp. of laboratory 57° F.).
156.	3 lbs. 2 oz.	0·52	0·5	4·37	Death, in 42 min. after the administration of physostigma.	*With atropia*, in 3 min., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{15}{50} \times \frac{15}{50}$. *After physostigma*, further dilatation to $\frac{17}{50} \times \frac{17}{50}$, occurred in 3 min., and continued until death. — After death, the size was in 4 min., $\frac{6}{50} \times \frac{5}{50}$.	*With atropia*, in 4 min., acceleration from 36 to 50 per 10 sec. *After physostigma*, the rate per 10 sec. was in 21 min., 42; and in 36 min., 24.	*With atropia*, none noted. *After physostigma*, the rate per 10 sec. was in 11 min., 13; in 21 min., 6; and in 24 min., 5. Afterwards, irregular and feeble gasps occurred until death.	*With atropia*, none noted. *After physostigma*, none. Neither defæcation nor urination occurred, nor was the secretion of any buccal gland increased.	*With atropia*, none noted. *After physostigma*, in 7 min., slight paralysis; and in 15 min., general flaccidity, which increased until death. Tremors and spasms frequently occurred. Fibrillary twitches were well marked in the earlier part of the experiment; but none were present after 20 min. —After death, rigor had not set in at 35 min.

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
157.	3 lbs. 5 oz.	1·1	1	4·6	Death, in 29 min. after the administration of physostigma.	*With atropia*, in 3 min., dilatation from $\frac{13}{50} \times \frac{12}{50}$ to $\frac{16}{50} \times \frac{16}{50}$. *After physostigma*, further dilatation soon took place to $\frac{18}{50} \times \frac{18}{50}$; and this size was maintained until death.—After death, in 5 min., the size was $\frac{14}{50} \times \frac{13}{50}$.	*With atropia*, in 4 min., acceleration from 39 to 52 per 10 sec. *After physostigma*, in 4 min., the rate per 10 sec. was 53. Twitches and tremors prevented any exact observations being subsequently made; but in 22 min., the impulse was rapid.	*With atropia*, none noted. *After physostigma*, the rate per 10 sec. was in 14 min., 18; in 19 min., 12; and in 20 min., 2. Afterwards, feeble gasps occurred at irregular intervals until death.	*With atropia*, none. *After physostigma*, neither defæcation nor urination occurred; but the secretion of certain buccal or bronchial glands was shown to be increased by moist sounds occasionally accompanying the respirations.	*With atropia*, none. *After physostigma*, in 8 min., slight paralysis; and in 15 min., general flaccidity, which increased until death. Tremors and feeble convulsive spasms frequently occurred; and fibrillary twitches were present in a very well-marked form until 17 min. after the administration of physostigma. Rigor had not set in at 1 hour after death.

SERIES I.—*continued.*

TABLE 8.—EXPERIMENTS WITH FOUR TIMES THE MINIMUM-LETHAL DOSE OF PHYSOSTIGMA (4·8 *grs. of Extract of Physostigma per Three Pounds Weight of Rabbit*).

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
158.	3 lbs.	0·1	0·1	4·8	Death, in 41 min. after the administration of physostigma.	*With atropia*, in 4 min. 30 sec., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{15}{50} \times \frac{15}{50}$. *After physostigma*, the size was, in 5 min., $\frac{16}{50} \times \frac{16}{50}$; in 9 min., $\frac{17}{50} \times \frac{17}{50}$; in 21 min., $\frac{10}{50} \times \frac{9}{50}$; in 25 min., $\frac{9}{50} \times \frac{8}{50}$; and in 39 min., $\frac{9}{50} \times \frac{8}{50}$.—After death it was, in 1 min., $\frac{9}{50} \times \frac{8}{50}$; in 15 min., $\frac{9}{50} \times \frac{8}{50}$; and in 1 hour 20 min., $\frac{10}{50} \times \frac{10}{50}$.	*With atropia*, in 4 min., acceleration from 39 to 52 per 10 sec. *After physostigma*, the rate per 10 sec. was, in 2 min., 52; in 4 min., 45; in 7 min., 39; in 25 min., 28; and in 30 min., 30.	*With atropia*, in 3 min., acceleration from 23 to 26 per 10 sec. *After physostigma*, the rate per 10 sec. was, in 4 min., 22; in 20 min., 18; in 24 min., 5; and in 24 min., 4. Afterwards, only very feeble and irregularly occurring respirations took place until death.	*With atropia*, none. *After physostigma*, in 8 min., the secretion of certain bronchial glands was slightly increased, but this ceased in a few minutes. In 20 min., 2 or 3 normal fæcal pellets were passed. There was no salivation nor urination.	*With atropia*, none. *After physostigma*, in 1 min. 30 sec., slight and infrequent fibrillary twitches, which soon became very well marked, but again became slight shortly before death. In 12 min., distinct paralysis, and in 22 min., general flaccidity. Frequently, tremors occurred, and, more rarely, there were spasms.—After death, the first appearance of rigor was at about 1 hour 20 min. (temp. of laboratory, 59° F.).

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Extract.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
159.	3 lbs. 1 oz.	0·15	0·15	4·9	Death, in 1 hour 9 min. after the administration of physostigma.	*With atropia*, in 3 min., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{16}{50} \times \frac{16}{50}$. *After physostigma*, the size was in 1 min., $\frac{17}{50} \times \frac{17}{50}$; in 37 min., $\frac{18}{50} \times \frac{18}{50}$; and in 1 hour 8 min., $\frac{17}{50} \times \frac{17}{50}$. — After death, it was, in 3 min., $\frac{15}{50} \times \frac{15}{50}$; in 6 min., $\frac{12}{50} \times \frac{12}{50}$; in 13 min., $\frac{10}{50} \times \frac{10}{50}$; and in 45 min., $\frac{13}{50} \times \frac{13}{50}$.	*With atropia*, in 4 min., acceleration from 42 to 57 per 10 sec. *After physostigma*, the rate per 10 sec. was in 3 min., 59; in 9 min., 49; in 50 min., 47; in 1 hour, 45; in 1 hour 3 min., 46; in 1 hour 5 min., 36; and in 1 hour 8 min., 36.	*With atropia*, none. The original rate was 32 per 10 sec. *After physostigma*, the rate per 10 sec. was in 3 min., 37; in 12 min., 20; in 22 min., 16; in 51 min., 15; and in 59 min., 6. — Afterwards, only gasping movements occurred irregularly.	*With atropia*, none. *After physostigma*, none. There was no defæcation, urination, nor salivation.	*With atropia*, none. *After physostigma*, in 2 min., slight and infrequent fibrillary twitches, which soon became well marked. In 7 min., slight paralysis; and in 27 min., general flaccidity. Tremors occurred frequently. — After death, the first appearance of rigor was at about 45 min. (temp. of laboratory, 58° F.).
160.	3 lbs.	0·2	0·2	4·8	Death, in 43 min. after the administration of physostigma.	*With atropia*, in 3 min., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{15}{50} \times \frac{15}{50}$. *After physostigma*, the size was in 7 min., $\frac{17}{50} \times \frac{17}{50}$; in 26 min., $\frac{14}{50} \times \frac{14}{50}$; in 32 min., $\frac{16}{50} \times \frac{16}{50}$; and in 43 min., $\frac{18}{50} \times \frac{18}{50}$. — After death, it was, in 1 min., $\frac{17}{50} \times \frac{17}{50}$; in 4 min., $\frac{14}{50} \times \frac{14}{50}$; in 9 min., $\frac{12}{50} \times \frac{12}{50}$; and in 57 min., $\frac{10}{50} \times \frac{10}{50}$.	*With atropia*, in 4 min., acceleration from 41 to 54 per 10 sec. *After physostigma*, the rate per 10 sec. was in 4 min., 45; in 7 min., 43; in 26 min., 37; in 32 min., 36; in 39 min., 22; and in 42 min., 19.	*With atropia*, in 3 min. 30 sec., slowing from 19 to 14 per 10 sec. *After physostigma*, the rate per 10 sec. was in 5 min., 17; in 10 min., 19; in 25 min., 12; in 32 min., 5; and in 35 min., 3.—Afterwards, only infrequent gasping movements occurred.	*With atropia*, none. *After physostigma*, none. There was no defæcation, urination, nor salivation.	*With atropia*, none. *After physostigma*, in 2 min., infrequent fibrillary twitches, which afterwards became only slightly developed. In 8 min., distinct paralysis; and in 28 min., general flaccidity. Frequently tremors occurred.— Rigor had not begun at 57 min. after death (temp. of laboratory 56° F.).
161	4 lbs. 2 oz.	0·275	0·2	6·6	Death, in 34 min. after the administration of physostigma.	*With atropia*, in 3 min., dilatation from $\frac{13}{50} \times \frac{12}{50}$ to $\frac{16}{50} \times \frac{15}{50}$. *After physostigma*, the size was in 7 min., $\frac{18}{50} \times \frac{18}{50}$; in 22 min., $\frac{14}{50} \times \frac{13}{50}$; and in 32 min., $\frac{12}{50} \times \frac{11}{50}$.—After death, it was, in 2 min., $\frac{10}{50} \times \frac{10}{50}$.	*With atropia*, in 4 min., acceleration from 40 to 58 per 10 sec. *After physostigma*, the rate per 10 sec. was in 3 min., 53; in 24 min., 44; in 28 min., 22; and in 30 min., 18.	*With atropia*, none. The original rate was 23 per 10 sec. *After physostigma*, the rate per 10 sec. was in 2 min., 18; in 26 min., 13; and in 28 min., 9. Afterwards, only feeble gasps occurred.	*With atropia*, none. *After physostigma*, in 4 min., the secretion of certain buccal glands was slightly increased, but only for a few minutes; and in 24 min., several normal fæcal pellets were passed. There was no urination.	*With atropia*, none. *After physostigma*, in 2 min., fibrillary twitches. In 8 min., slight paralysis; and in 22 min., general flaccidity. Tremors and spasms frequently occurred.—After death, there was decided but not strong rigor, at 1 hour 10 min. (temp. of laboratory, 59° F.).
162.	3 lbs. 12 oz.	0·37	0·3	6·	Death, in 1 hour 24 min. after the administration of physostigma.	*With atropia*, in 4 min., dilatation from $\frac{15}{50} \times \frac{14}{50}$ to $\frac{17}{50} \times \frac{17}{50}$. *After physostigma*, the size was in 30 sec., $\frac{18}{50} \times \frac{18}{50}$; and in 1 hour 24 min., $\frac{18}{50} \times \frac{18}{50}$. — After death, it was, in 2 min., $\frac{16}{50} \times \frac{16}{50}$; and in 22 min., $\frac{16}{50} \times \frac{16}{50}$.	*With atropia*, in 3 min. 30 sec., acceleration from 42 to 59 per 10 sec. *After physostigma*, the rate per 10 sec. was in 4 min., 54; in 56 min., 60; in 1 hour, 46; in 1 hour 5 min., 41; in 1 hour 14 min., 37; and in 1 hour 22 min., 25.	*With atropia*, none. The original rate was 19 per 10 sec. *After physostigma*, the rate per 10 sec. was in 17 min., 16; in 48 min., 13; in 57 min., 8; in 59 min., 4; and in 1 hour 14 min., 3. Afterwards, only infrequent gasps occurred.	*With atropia*, none. *After physostigma*, none. There was no defæcation, urination, nor salivation.	*With atropia*, none. *After physostigma*, in 1 min. 30 sec., infrequent fibrillary twitches, which soon became very well marked, but were only slight shortly before death. In 6 min., slight paralysis; and in 55 min., general flaccidity. Tremors frequently occurred. — After death, there was no rigor at 23 min.

SERIES II.—DETERMINATION OF THE LIMITS OF ANTAGONISM WHEN ATROPIA IS ADMINISTERED FIVE MINUTES AFTER PHYSOSTIGMA.

TABLE 1.—Experiments with half the Minimum-Lethal Dose of Physostigma (0·06 *gr. of Sulphate of Physostigmia per Three Pounds Weight of Rabbit*).

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
163.	2 lbs. 14 oz.	0·058	4·79	5	Recovery.	*With physostigma*, none. The original size was $\frac{12}{50} \times \frac{12}{50}$. *After atropia*, the size was in 4 min., $\frac{16}{50} \times \frac{16}{50}$; and in 1 hour, $\frac{15}{50} \times \frac{15}{50}$. —On the following day, it was $\frac{17}{50} \times \frac{17}{50}$.	*With physostigma*, in 4 min., slowing from 39 to 38 per 10 sec. *After atropia*, the rate per 10 sec. was in 2 min., 58; in 4 min., 60; in 16 min., 62; and in 1 hour, 51.—On the following day, it was 50; and on the 3rd day, 40.	*With physostigma*, in 3 min., acceleration from 25 to 28 per 10 sec. *After atropia*, the rate per 10 sec. was in 3 min., 32; in 14 min., 18; and in 1 hour 2 min., 22.—On the following day, it was 26; and on the 3d day, 22.	*With physostigma*, none. *After atropia*, none. There was no defæcation, urination, nor salivation during the 1 hour and 5 min. of continuous observation.	*With physostigma*, in 1 min., slight and infrequent fibrillary twitches. *After atropia*, the fibrillary twitches soon became pretty well marked, and they continued so for more than 1 hour. In 15 min., slight paralysis, which did not increase within 50 min. There were no tremors nor spasms.
164.	2 lbs. 14 oz.	0·058	6·7	7	Recovery.	*With physostigma*, none. The original size was $\frac{11}{50} \times \frac{11}{50}$. *After atropia*, the size was in 1 min. 30 sec., $\frac{14}{50} \times \frac{14}{50}$; in 3 min., $\frac{16}{50} \times \frac{16}{50}$; in 14 min., $\frac{15}{50} \times \frac{15}{50}$; and in 1 hour 14 min., $\frac{14}{50} \times \frac{14}{50}$.—On the following day, it was $\frac{16}{50} \times \frac{17}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 40 to 32 per 10 sec. *After atropia*, the rate per 10 sec. was in 4 min., 53; in 30 min., 38; in 1 hour 18 min., 28; in 1 hour 40 min., 32; and in 2 hours 13 min., 36.—On the following day, it was 33; and on the 3rd day, 60.	*With physostigma*, in 3 min. 30 sec., slowing from 22 to 19 per 10 sec. *After atropia*, the rate per 10 sec. was in 3 min., 20; in 14 min., 15; in 1 hour 16 min, 17; in 1 hour 35 min., 19; and in 2 hours 14 min., 13.—On the following day, it was 12; and on the 3rd day, 13.	*With physostigma*, none. *After atropia*, none. There was no defæcation, urination, nor salivation during the 2 hours and 15 min. of continuous observation.	*With physostigma*, in 2 min., slight and infrequent fibrillary twitches. *After atropia*, in 14 min., the fibrillary twitches had disappeared. In 12 min., slight paralysis; and in 40 min., decided paralysis, which had not lessened in 2 hours 15 min. Feeble tremors and starts occasionally took place.
165.	2 lbs. 14 oz.	0·058	6·87	7·5	Recovery.	*With physostigma*, none. The original size was $\frac{12}{50} \times \frac{12}{50}$. *After atropia*, the size was in 2 min., $\frac{16}{50} \times \frac{16}{50}$; and in 4 hours 5 min., $\frac{16}{50} \times \frac{16}{50}$.—On the following day, it was $\frac{17}{50} \times \frac{17}{50}$; and on the 7th day, $\frac{16}{50} \times \frac{16}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 43 to 32 per 10 sec. *After atropia*, the rate per 10 sec. was in 2 min., 58; in 4 min., 63; in 7 min., 67; in 30 min., 50; in 1 hour, 43; in 1 hour 25 min., 38; and in 2 hours 35 min., 32.—On the following day, it was 42; and on the 7th day, 40.	*With physostigma*, none. The original rate was 23 per 10 sec. *After atropia*, the rate per 10 sec. was in 5 min., 26; in 10 min., 30; in 31 min., 27; in 57 min., 17; and in 4 hours, 16.	*With physostigma*, none. *After atropia*, none. There was no defæcation, urination, nor salivation during the 4 hours and 5 min. of continuous observation.	*With physostigma*, in 1 min., slight and infrequent fibrillary twitches. *After atropia*, the fibrillary twitches soon became well marked, but in 4 hours they had altogether disappeared. In 15 min., slight paralysis; in 45 min., well-marked paralysis; and in 3 hours 40 min., no paralysis. Frequently tremors and feeble spasms occurred.

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
166.	2 lbs. 14 oz.	0·058	7·45	8	Death, in more than 1 hour 40 min. after the administration of physostigma.	*With physostigma*, none. The original size was $\frac{13}{50} \times \frac{12}{50}$. *After atropia*, the size was in 3 min., $\frac{17}{50} \times \frac{17}{50}$; in 50 min., $\frac{17}{50} \times \frac{17}{50}$; and in 1 hour 10 min., $\frac{16}{50} \times \frac{16}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 39 to 38 per 10 sec. *After atropia*, the rate per 10 sec. was in 4 min., 49; in 6 min., 56; in 28 min., 42; and in 40 min., about 24. Afterwards, the impulse was too feeble to be counted.	*With physostigma*, none. The original rate was 17 per 10 sec. *After atropia*, the rate per 10 sec. was in 4 min., 16; in 7 min., 14; in 50 min., 12; and in 1 hour 38 min., 8.	*With physostigma*, none. *After atropia*, none. There was no defæcation, urination, nor salivation during the 1 hour and 40 minutes of continuous observation.	*With physostigma*, in 2 min., slight and infrequent fibrillary twitches. *After atropia*, in 24 min., the fibrillary twitches had disappeared. In 14 min., slight paralysis; in 35 min., well-marked paralysis; and in 1 hour 40 min., well-marked paralysis. Frequently, feeble tremors and starts occurred.
167.	3 lbs. 2 oz.	0·062	8·5	8·16	Death, in 2 hours 31 min. after the administration of physostigma.	*With physostigma*, none. The original size was $\frac{14}{50} \times \frac{13}{50}$. *After atropia*, the size was in 3 min., $\frac{17}{50} \times \frac{17}{50}$; in 9 min., $\frac{18}{50} \times \frac{18}{50}$; in 15 min., $\frac{17}{50} \times \frac{17}{50}$; and in 1 hour 26 min., $\frac{17}{50} \times \frac{17}{50}$.—After death, it was in 2 min., $\frac{16}{50} \times \frac{16}{50}$; in 5 min., $\frac{14}{50} \times \frac{14}{50}$; and in 16 min., $\frac{12}{50} \times \frac{12}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 38 to 37 per 10 sec. *After atropia*, the rate per 10 sec. was in 4 min., 48; in 13 min., 52; in 30 min., 49; in 43 min., 42; and in 45 min., 30. Afterwards, the impulse was too feeble to be counted.	*With physostigma*, none. The original rate was 16 per 10 sec. *After atropia*, the rate per 10 sec. was in 4 min., 20; in 7 min. 29; in 29 min., 16; in 57 min., 10; and in 2 hours 22 min., 6. Afterwards, only infrequent gasps occurred.	*With physostigma*, none. *After atropia*, none. There was no defæcation, urination, nor salivation.	*With physostigma*, in 2 min., slight and infrequent fibrillary twitches. *After atropia*, in 50 min., the fibrillary twitches had altogether disappeared. In 30 min., slight paralysis; in 53 min., well-marked paralysis; and in 2 hours hours 16 min., general flaccidity. Frequently, tremors and feeble spasms occurred.—After death, there was no rigor at 28 min.

SERIES II.—*continued.*

TABLE 2.—EXPERIMENTS WITH THE MINIMUM-LETHAL DOSE OF PHYSOSTIGMA (0·12 *gr. of Sulphate of Physostigmia per Three Pounds Weight of Rabbit*).

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
168.	3 lbs. 12 oz.	0·15	0·012	0·01	Death, in 1 hour 15 min. after the administration of physostigma.	*With physostigma*, in 4 min., dilatation from $\frac{13}{50} \times \frac{12}{50}$ to $\frac{14}{50} \times \frac{13}{50}$. *After atropia*, the size was in 4 min., $\frac{17}{50} \times \frac{17}{50}$; in 13 min., about $\frac{19}{50} \times \frac{19}{50}$; in 35 min., $\frac{14}{50} \times \frac{14}{50}$; in 39 min., $\frac{12}{50} \times \frac{11}{50}$; in 43 min., $\frac{15}{50} \times \frac{14}{50}$; in 55 min., $\frac{11}{50} \times \frac{10}{50}$; and in 1 hour 3 min., $\frac{14}{50} \times \frac{13}{50}$, which size remained until death. — After death, the size was in 1 min., $\frac{11}{50} \times \frac{10}{50}$; and in 3 min., $\frac{10}{50} \times \frac{9}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 42 to 37 per 10 sec. *After atropia*, the rate per 10 sec. was in 7 min., 47; in 11 min., 43; and it gradually slowed from this until death.	*With physostigma*, none noted. *After atropia*, the rate per 10 sec. was in 13 min., 18. Soon after it began to slow, and also the movements began to get feeble, until in 50 min., only rare gasps occurred.	*With physostigma*, none. *After atropia*, in 30 min., slight salivation occurred, and continued until death. In 40 min., one fæcal pellet was passed. No urine was voided.	*With physostigma*, in 2 min. 30 sec., faint and infrequent fibrillary twitches. *After atropia*, in 5 min., slight paralysis; in 8 min., decided paralysis; and in 28 min., general flaccidity. Tremors frequently occurred, and fibrillary twitches continued in a well-marked form until death.

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
169.	3 lbs. 3 oz.	0·127	0·016	0·015	Death, in 17 min. after the administration of physostigma.	*With physostigma*, none noted. *After atropia*, contraction soon occurred; and in 7 min., the size was $\frac{7}{50} \times \frac{6}{50}$.	*With physostigma*, none noted. *After atropia*, none noted.	*With physostigma*, none noted. *After atropia*, slowing occurred until death, and the movements were greatly embarrased by mucus in the larynx and fluid in the mouth.	*With physostigma*, none noted. *After atropia*, in 6 min., several normal fæcal pellets were passed; in 8 min., slight salivation had occurred, which increased considerably before death.	*With physostigma*, none noted. *After physostigma*, in 6 min., distinct paralysis; and in 10 min., general flaccidity. Fibrillary twitches were present until death in a well-marked form.
170. *a*	3 lbs. 3 oz. [Experiment *b* was performed eight days after experiment *a*.]	0·128	0·02	0·02	Recovery.	*With physostigma*, none. *After atropia*, the size was in 4 min., $\frac{10}{50} \times \frac{9}{50}$; in 12 min., $\frac{14}{50} \times \frac{14}{50}$; in 20 min., $\frac{16}{50} \times \frac{16}{50}$; and in 1 hour, $\frac{16}{50} \times \frac{16}{50}$.—On the following day it was $\frac{10}{50} \times \frac{9}{50}$.	*With physostigma*, none noted. *After atropia*, no observations were made until the following day, when the rate per 10 sec. was 36. On the 5th day, it was 46 per 10 sec.	*With physostigma*, none. *After atropia*, in 26 min., slowing had occurred from the original rate of 19 to 15 per 10 sec.	*With physostigma*, none. *After atropia*, in 3 min., the secretion of certain buccal glands was slightly increased; in 6 min., salivation occurred, but it had ceased by 13 min. In 1 hour 8 min., a little urine was voided.	*With physostigma*, in 2 min., infrequent fibrillary twitches. *After atropia*, in 5 min., slight paralysis; in 30 min., general flaccidity; and in 1 hour 10 min., only slight paralysis. Tremors and general feeble spasms frequently occurred, and fibrillary twitches were present in a well-marked form until after 1 hour 10 min.
b	3 lbs. 4 oz.	0·13 (= 0·12 gr. p. 3 lbs.	0	0	Death, in 13 min.	—	—	—	—	—
171. *a*	3 lbs. 6 oz. [Experiment *b* was performed eleven days after experiment *a*.]	0·135	0·056	0·05	Recovery.	*With physostigma*, none. *After atropia*, the size was in 1 min., $\frac{11}{50} \times \frac{10}{50}$; in 10 min., $\frac{16}{50} \times \frac{16}{50}$; in 15 min., $\frac{18}{50} \times \frac{18}{50}$; in 40 min., $\frac{15}{50} \times \frac{15}{50}$; in 1 hour 25 min., $\frac{13}{50} \times \frac{12}{50}$; and in 2 hours 30 min., $\frac{10}{50} \times \frac{9}{50}$.—On the following day, it was $\frac{11}{50} \times \frac{10}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 39 to 34 per 10 sec. *After atropia*, the rate per 10 sec. was in 10 min., 40; and in 2 hours 30 min., 37.—On the following day it was 37.	*With physostigma*, in 3 min., slowing from 16 to 13 per 10 sec. *After atropia*, in 18 min., the rate per 10 sec. was 37. Afterwards, slowing occurred, and in 2 hours 30 min. the rate per 10 sec. was 12.	*With physostigma*, none. *After atropia*, in 3 min., the secretion of certain buccal glands was slightly increased, but only for a few minutes; and in 2 hours 15 min. increase again occurred, and continued for at least an hour, the respirations being often noisy. In 40 min., several normal fæcal pellets were passed; in 7 hours, slightly pultaceous fæces; and, afterwards, on several occasions, semi-liquid fæces.	*With physostigma*, none. *After atropia*, in 3 min., slight extension of the limbs, which became well marked in 5 min. In 10 min., distinct paralysis; in 40 minutes, well-marked paralysis; and in 1 hour 30 min., almost no paralysis. Tremors and starts frequently occurred; and fibrillary twitches were very well developed, and present for at least 2 hours 40 min.
b	3 lbs. 6 oz.	0·135 (= 0·12 gr. p. 3 lbs.)	0	0	Death, in 37 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
172. *a* [Experiment *b* was performed ten days after experiment *a*.]	3 lbs. 3 oz.	0·127	0·11	0·1	Recovery.	*With physostigma*, none. *After atropia*, the size was in 8 min., $\frac{18}{50} \times \frac{16}{50}$; and in 40 min., $\frac{18}{50} \times \frac{18}{50}$.—On the following day it was $\frac{17}{50} \times \frac{17}{50}$; and on the 7th day, $\frac{15}{50} \times \frac{14}{50}$.	*With physostigma*, none noted. *After atropia*, no accurate observations could be made for more than 1 hour 20 min., on account of the very frequent fibrillary twitches.—On the following day the rate per 10 sec. was 40.	*With physostigma*, none noted. *After atropia*, in 40 min., slowing to 19 per 10 sec. from the original rate of 23 per 10 sec.	*With physostigma*, none. *After atropia*, in 1 min. 30 sec., the secretion of certain buccal glands was slightly increased, but only for a few minutes. In 20 min., pultaceous fæces were passed.	*With physostigma*, none. *After atropia*, in 7 min., slight extension of the limbs, and unsteadiness. In 14 min., slight paralysis, which did not perceptibly increase, but had almost disappeared in 1 hour 30 min. Occasionally, gentle tremors occurred. Fibrillary twitches were very well developed, and lasted for more than 1 hour 30 min.
	3 lbs. 2 oz.	0·125 (= 0·12 gr. p. 3 lbs.)	0	0	Death, in 29 min.	—	—	—	—	—
173. *a* [Experiment *b* was performed nine days after experiment *a*.]	3 lbs.	0·12	0·2	0·2	Recovery.	*With physostigma*, none. *After atropia*, the size was in 2 min., $\frac{15}{50} \times \frac{14}{50}$; and in 9 min., $\frac{17}{50} \times \frac{17}{50}$, which size remained for more than 1 hour.—On the following day, the size was $\frac{12}{50} \times \frac{11}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 42 to 32 per 10 sec. *After atropia*, the rate could not accurately be ascertained for more than 1 hour 20 min., on account of the frequent occurrence of fibrillary twitches.—On the following day, the rate per 10 sec. was 32.	*With physostigma*, none. *After atropia*, the rate per 10 sec. was in 3 min., 14; and in 9 min., 23.	*With physostigma*, in 4 min. 30 sec., the secretion of certain buccal glands were slightly increased. *After atropia*, the above increase ceased in a few minutes. Neither defæcation, urination, nor salivation occurred during the 2 hours of continuous observation.	*With physostigma*, in 2 min., infrequent fibrillary twitches. *After atropia*, the fibrillary twitches soon became very well marked, and continued so for at least 1 hour 40 min. In 9 min., slight paralysis, which did not distinctly increase during the succeeding hour and 40 min.
	3 lbs. 3 oz.	0·127 (= 0·12 gr. p. 3 lbs.)	0	0	Death, in 13 min.	—	—	—	—	—
174. *a* [Experiment *b* was performed nine days after experiment *a*.]	3 lbs.	0·12	0·5	0·5	Recovery.	*With physostigma*, in 4 min., dilatation from $\frac{10}{50} \times \frac{9}{50}$ to $\frac{11}{50} \times \frac{10}{50}$. *After atropia*, the size was in 2 min., $\frac{15}{50} \times \frac{15}{50}$; in 5 min., $\frac{16}{50} \times \frac{16}{50}$; in 45 min., $\frac{15}{50} \times \frac{15}{50}$; in 1 hour 10 min., $\frac{10}{50} \times \frac{9}{50}$; and in 2 hours 10 min., $\frac{9}{50} \times \frac{9}{50}$.—On the following day, it was $\frac{9}{50} \times \frac{8}{50}$.	*With physostigma*, in 4 min. 20 sec., acceleration from 40 to 35 per 10 sec. *After atropia*, the rate per 10 sec. was in 4 min., 46; in 7 min., 53; in 11 min., 62; in 45 min., 48; and in 2 hours 10 min., 40—On the following day, it was 40.	*With physostigma*, in 3 min., slowing from 20 to 15 per 10 sec. *After atropia*, the rate per 10 sec. was in 6 min., 26; in 25 min., 18; and in 2 hours 12 min., 14.	*With physostigma*, none noted. *After atropia*, in 1 hour, somewhat pultaceous fæcal pellets were passed. No urination nor salivation occurred during the 2 hours of continuous observation.	*With physostigma*, in 2 min., infrequent fibrillary twitches. *After atropia*, the fibrillary twitches soon became well marked, and they continued for more than 2 hours. In 6 min., some stiffness in the limbs; in 13 min, distinct paralysis, which increased a little and then lessened, so that in 1 hour 30 min., there was almost no paralysis. Occasionally, feeble tremors occurred.
	3 lbs. 3 oz.	0·127 (= 0·12 gr. p. 3 lbs.)	0	0	Death, in 22 min.	—	—	—	—	—

Number of Experiment.		Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
175.	*a*	3 lbs. 11 oz. [Experiment *b* was performed nine days after experiment *a*.]	0·147	1·2	1	Recovery.	*With physostigma*, none. *After atropia*, the size was in 2 min., $\frac{18}{50} \times \frac{18}{50}$; and this size remained for more than 2 hours.—On the following day, the size was $\frac{19}{50} \times \frac{19}{50}$; on the 3d day, $\frac{16}{50} \times \frac{16}{50}$; and on the 9th day, $\frac{14}{50} \times \frac{14}{50}$.	*With physostigma*, in 4 min., slowing from 41 to 33 per 10 sec. *After atropia*, the rate per 10 sec. was in 5 min., 51; in 30 min., 53; and in 2 hours, 55.—On the following day it was 45; and on the 3d day, 42.	*With physostigma*, in 3 min., slowing from 22 to 19 per 10 sec. *After atropia*, in 30 min., the rate per 10 sec. was 27; and in 1 hour, 15.	*With physostigma*, none. *After atropia*, none. Neither defæcation, urination, nor salivation occurred during the 2 hours of continuous observation.	*With physostigma*, in 2 min., infrequent fibrillary twitches. *After atropia*, the fibrillary twitches became well marked, and continued so for at least 2 hours. In 10 min., slight paralysis; in 25 min., pretty well-marked paralysis; and in 1 hour 20 min., almost no paralysis. Rarely feeble tremors occurred.
	b	3 lbs. 11 oz.	0·147 (= 0·12 gr. p. 3 lbs.)	0	0	Death, in 31 min.	—	—	—	—	—
176.	*a*	3 lbs. 2½ oz. [Experiment *b* was performed ten days after experiment *a*.]	0·126	2·08	2	Recovery.	*With physostigma*, in 4 min. 20 sec., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{13}{50} \times \frac{12}{50}$. *After atropia*, the size was in 4 min., $\frac{15}{50} \times \frac{15}{50}$; in 30 min., $\frac{18}{50} \times \frac{18}{50}$; and in 2 hours 15 min., $\frac{18}{50} \times \frac{18}{50}$.—On the following day, it was $\frac{14}{50} \times \frac{14}{50}$; and on the 9th day, $\frac{12}{50} \times \frac{11}{50}$.	*With physostigma*, in 4 min., slowing from 39 to 36 per 10 sec. *After atropia*, the rate per 10 sec. was in 5 min., 51; in 16 min., 58; in 40 min., 55; in in 1 hour, 46; and in 1 hour 30 min., 34.—On the following day, it was 38; and on the 3d day, 40.	*With physostigma*, in 3 min., slowing from 16 to 15 per 10 sec. *After atropia*, the rate per 10 sec. was in 4 min., 14; in 30 min., 17; and in 1 hour, 14.	*With physostigma*, none. *After atropia*, in 40 min. and in 2 hours 20 min., urine was voided. Neither defæcation nor salivation occurred during the 2 hours 30 min. of continuous observation.	*With physostigma*, in 2 min., infrequent fibrillary twitches. *After atropia*, the fibrillary twitches became well marked, and continued for more than 2 hours 30 min. In 25 min., slight paralysis; in 40 min., well-marked paralysis; and in 2 hours, almost no paralysis. Very gentle tremors occasionally occurred.
	b	3 lbs. 2 oz.	0·125 (= 0·12 gr. p. 3 lbs.)	0	0	Death, in 25 min.	—	—	—	—	—
177.	*a*	3 lbs. 4 oz. [Experiment *b* was performed three days after experiment *a*.]	0·13	2·6	2·4	Recovery.	*With physostigma*, in 3 min. 30 sec., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{13}{50} \times \frac{12}{50}$. *After atropia*, the size was in 4 min., $\frac{17}{50} \times \frac{17}{50}$; and in 1 hour, $\frac{18}{50} \times \frac{18}{50}$.—On the following day, it was $\frac{17}{50} \times \frac{17}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 41 to 31 per 10 sec. *After atropia*, the rate per 10 sec. was in 6 min., 58; in 18 min., 60; and in 1 hour, 60.—On the following day, it was 37; on the 3d day, 34; and on the 4th day, 40.	*With physostigma*, the original rate of 31 per 10 sec. was continued. *After atropia*, the rate per 10 sec. was in 6 min., 33; in 15 min., 31; and in 32 min., 20.	*With physostigma*, in 4 min. 40 sec., the secretion of certain buccal glands was slightly increased. *After atropia*, in 35 min., one normal fæcal pellet was passed. Neither urination nor salivation occurred during the 1 hour and 10 min. of continuous observation.	*With physostigma*, in 2 min., infrequent and slight fibrillary twitches. *After atropia*, the fibrillary twitches remained only slightly marked. In 10 min., extension of the limbs; in 11 min., slight paralysis; and in 20 min., pretty well-marked paralysis. Feeble tremors occurred, and there was one opisthotonic convulsion.
	b	3 lbs. 1 oz.	0·12	0	0	Death, in 21 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
178. *a* [Experiment *b* was performed nine days after experiment *a*.]	3 lbs.	0·12	2·5	2·5	Recovery.	*With physostigma*, none noted. *After atropia*, the size was in 1 min., $\frac{12}{50} \times \frac{11}{50}$; and in 3 min., $\frac{15}{50} \times \frac{15}{50}$, which size was present in 2 hours.—On the following day, it was $\frac{16}{50} \times \frac{16}{50}$.	*With physostigma*, in 4 min., slowing from 41 to 37 per 10 sec. *After atropia*, the rate per 10 sec. was in 3 min., 51; in 15 min., 61; and in 2 hours, 57.—On the following day, it was 37; and on the 3d day, 41.	*With physostigma*, in 3 min., slowing from 17 to 13 per 10 sec. *After atropia*, the rate per 10 sec. was in 5 min., 14; in 14 min., 16; in 1 hour 25 min., 18; and in 2 hours, 13.	*With physostigma*, none noted. *After atropia*, in 20 min., some urine was voided. Neither defæcation nor salivation occurred, nor was the secretion of any buccal gland increased during the 2 hours of continuous observation.	*With physostigma*, in 3 min., infrequent and slight fibrillary twitches. *After atropia*, in 8 min., slight paralysis; in 20 min., well-marked paralysis; and in 2 hours, almost no paralysis. Only at 21 min., a few slight tremors occurred. Fibrillary twitches were present in a very slight form.
	b 3 lbs.	0·12	0	0	Death, in 20 min.	—	—	—	—	—
179.	4 lbs. 4 oz.	0·18	3·9	2·6	Death, in 37 min. after the administration of physostigma.	*With physostigma*, none. *After atropia*, the size was in 3 min., $\frac{17}{50} \times \frac{17}{50}$; and in 22 min., $\frac{17}{50} \times \frac{17}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 40 to 39 per 10 sec. *After atropia*, the rate per 10 sec. was in 4 min., 48. In order to avoid interference with the result of the experiment, no further observation was made.	*With physostigma*, in 2 min., acceleration from 32 to 35 per 10 sec. *After atropia*, the rate per 10 sec. was in 5 min., 33; in 25 min., 20; and in 28 min., 16. Latterly, the respirations were very feeble, and they ultimately became gasping.	*With physostigma*, none noted. *After atropia*, none. Neither defæcation nor urination occurred, nor was the secretion of any buccal gland increased.	*With physostigma*, in 2 min., infrequent and slight fibrillary twitches. *After physostigma*, in 8 min., slight paralysis, which increased until death. Tremors occurred rarely, but excited and somewhat spasmodic movements frequently took place. Fibrillary twitches became well marked and continued so until death.
180.	2 lbs. 11 oz.	0·11	2·4	2·7	Death, in 29 min. after the administration of physostigma.	*With physostigma*, none. The original size was $\frac{14}{50} \times \frac{13}{50}$. *After atropia*, the size was in 1 min. 30 sec., $\frac{15}{50} \times \frac{15}{50}$; in 2 min., $\frac{16}{50} \times \frac{16}{50}$; and in 28 min. 30 sec., $\frac{16}{50} \times \frac{16}{50}$.—After death, it was in 1 min. 30 sec., $\frac{14}{50} \times \frac{14}{50}$; in 2 min., $\frac{12}{50} \times \frac{12}{50}$; in 9 min., $\frac{5}{50} \times \frac{4}{50}$; and in 18 min., $\frac{7}{50} \times \frac{6}{50}$.	*With physostigma*, in 4 min. 30 sec, slowing from 41 to 32 per 10 sec. *After atropia*, the rate per 10 sec. was in 3 min., 46; and in 6 min., 55.	*With physostigma*, none; the original rate was 21 per 10 sec. *After atropia*, the rate per 10 sec. was in 2 min., 23; and in 16 min., 21. In 19 min., infrequent gasps only occurred, and were continued until death.	*With physostigma*, none noted. *After atropia*, none.	*With physostigma*, in 2 min., infrequent and slight fibrillary twitches. *After atropia*, in 8 min., decided paralysis; and in 18 min., general flaccidity, which continued until death, accompanied with feeble spasms. Fibrillary twitches were present in a very slight form.
181.	3 lbs.	0·12	2·8	2·8	Death, in 43 min. after the administration of physostigma.	*With physostigma*, in 2 min., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{13}{50} \times \frac{13}{50}$. *After atropia*, the size was in 2 min., $\frac{16}{50} \times \frac{17}{50}$; in 4 min., $\frac{17}{50} \times \frac{18}{50}$; and in 38 min., $\frac{16}{50} \times \frac{17}{50}$.—After death, it was in 2 min., $\frac{14}{50} \times \frac{15}{50}$; in 4 min., $\frac{12}{50} \times \frac{12}{50}$; in 10 min., $\frac{11}{50} \times \frac{10}{50}$; and in 20 min., $\frac{18}{50} \times \frac{12}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 32 to 26 per 10 sec. *After atropia*, the rate per 10 sec. was in 3 min., 43; in 28 min., about 68; in 33 min., 58; and in 37 min., 42.	*With physostigma*, in 3 min. 30 sec., acceleration from 26 to 28 per 10 sec. *After atropia*, the rate per 10 sec. was in 3 min., 27; in 22 min., 15; in 26 min., 13; in 33 min., 7; and in 36 min., 1. Afterwards, gasps occurred at irregular intervals until death.	*With physostigma*, none noted. *After atropia*, none. Neither defæcation nor urination occurred, nor was the secretion of any buccal gland increased.	*With physostigma*, in 2 min., infrequent and slight fibrillary twitches. *After atropia*, in 15 min., slight paralysis; and in 21 min., well-marked paralysis, which increased until death. Tremors occasionally took place. Fibrillary twitches became well developed, but they diminished after 24 min.—Rigor began to set in at about 40 min. after death (temp. of laboratory, 61° F.).

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
182.	3 lbs. 4 oz.	0·13	3·25	3	Death, in 1 hour and 4 min. after the administration of physostigma.	*With physostigma*, none. The original size was $\frac{13}{50} \times \frac{12}{50}$. *After atropia*, the size was in 2 min., $\frac{15}{50} \times \frac{15}{50}$; in 8 min., $\frac{16}{50} \times \frac{16}{50}$; in 55 min., $\frac{17}{50} \times \frac{17}{50}$; and in 59 min., $\frac{17}{50} \times \frac{17}{50}$.—After death, it was in 1 min., $\frac{10}{50} \times \frac{10}{50}$; in 5 min., $\frac{7}{70} \times \frac{6}{50}$; and in 28 min., $\frac{10}{50} \times \frac{10}{50}$.	*With physostigma*, in 4 min., slowing from 41 to 36 per 10 sec. *After atropia*, the rate per 10 sec. was in 4 min., 53; in 12 min., 61; and in 59 min., 38.	*With physostigma*, in 2 min. 30 sec., acceleration from 20 to 23 per 10 sec. *After atropia*, the rate per 10 sec. was in 6 min., 25; in 48 min., 15; in 52 min., 12; and in 56 min., 2, and gasping.	*With physostigma*, none noted. *After atropia*, in 52 min., a little urine was voided. Neither defæcation nor salivation occurred, nor did any moist sounds accompany the respirations.	*With physostigma*, in 2 min., infrequent and slight fibrillary twitches. *After atropia*, in 22 min., slight paralysis; and in 40 min., well-marked paralysis and some general flaccidity. Occasionally, feeble tremors occurred. Fibrillary twitches were pretty well marked until 25 min., but afterwards they became extremely slight.—Rigor began to set in at about 45 min. after death (temp. of laboratory, 60° F.).
183.	3 lbs.	0·12	3·2	3·2	Death, in 54 min. after the administration of physostigma.	*With physostigma*, none. The original size was $\frac{13}{50} \times \frac{12}{50}$. *After atropia*, the size was in 3 min., $\frac{17}{50} \times \frac{17}{50}$; and it continued so until death.—After death, it was in 2 min., $\frac{15}{50} \times \frac{15}{50}$; in 4 min., $\frac{13}{50} \times \frac{12}{50}$; and in 29 min., $\frac{14}{50} \times \frac{13}{50}$.	*With physostigma*, in 4 min., slowing from 43 to 35 per 10 sec. *After atropia*, the rate per 10 sec. was in 33 min., 52; in 40 min., 50; in 43 min., 48; in 45 min., 39; and in 48 min. 30 sec., 36.	*With physostigma*, in 2 min., slowing from 26 to 16 per 10 sec. *After atropia*, the rate per 10 sec. was in 15 min., 31; in 25 min., 18; in 34 min., 13; in 38 min., 8; and in 42 min., 3. Only feeble gasps afterwards occurred.	*With physostigma*, none noted. *After atropia*, in 1 min., the secretion of certain buccal glands was slightly increased, but only for 2 or 3 min. There was no defæcation, urination, nor salivation.	*With physostigma*, in 1 min. 30 sec., infrequent and slight fibrillary twitches. *After atropia*, the fibrillary twitches increased, but they disappeared at least 15 min. before death. In 11 min., slight paralysis; and in 30 min., general flaccidity. Frequently, tremors and feeble spasms occurred.—After death, there was no rigor in 40 min.; but general rigor was present in 2 hours (temp. of laboratory, 62° F.).
184.	3 lbs. 5 oz.	0·132	4·4	4	Death, in 31 min. after the administration of physostigma.	*With physostigma*, none. The original size was $\frac{14}{50} \times \frac{13}{50}$. *After atropia*, the size was in 5 min., $\frac{17}{50} \times \frac{17}{50}$; and it continued so until death.—After death, the size was in 30 sec., $\frac{14}{50} \times \frac{13}{50}$; in 3 min., $\frac{11}{50} \times \frac{9}{50}$; and in 13 min., $\frac{12}{50} \times \frac{11}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 42 to 40 per 10 sec. *After atropia*, the rate per 10 sec. was in 4 min., 62; in 19 min., 58; in 23 min., 57; in 22 min., 52; and in 25 min. 30 sec., 40.	*With physostigma*, in 4 min., slowing from 31 to 25 per 10 sec. *After atropia*, the rate per 10 sec. was in 6 min., 38; in 14 min., 16; in 18 min., 8; and in 20 min., 5.—Afterwards feeble gasps occurred at irregular intervals until death.	*With physostigma*, none noted. *After atropia*, none. There was not any defæcation, urination, or salivation.	*With physostigma*, in 2 min., infrequent and slight fibrillary twitches. *After atropia*, in 6 min., slight paralysis; and in 20 min., general flaccidity. Tremors and starts frequently occurred. Fibrillary twitches became well developed, but they disappeared before death.—Rigor first appeared at 1 hour after death (temp. of laboratory, 61° F.).

TABLE 3.—Experiments with One and a half times the Minimum-Lethal Dose of Physostigma (0·18 *gr. of Sulphate of Physostigmia per Three Pounds Weight of Rabbit*).

Number of Experiment.		Weight of Rabbit	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
185.		3 lbs. 2 oz.	0·187	0·03	0·03	Death, in 25 min. after the administration of physostigma.	*With physostigma*, none. The original size was $\frac{11}{50} \times \frac{10}{50}$. *After atropia*, the size was in 13 min., $\frac{9}{50} \times \frac{8}{50}$; and in 18 min., $\frac{8}{50} \times \frac{7}{50}$. —After death, the size was in 1 min., $\frac{6}{50} \times \frac{6}{50}$; in 2 min., $\frac{5}{50} \times \frac{5}{50}$; and in 22 min., $\frac{6}{50} \times \frac{6}{50}$.	*With physostigma*, none noted. *After atropia*, no observations were made.	*With physostigma*, none noted. *After atropia*, in 13 min., the respirations were laboured and impeded by mucus and saliva. In 11 min., gasps only occurred.	*With physostigma*, none. *After atropia*, in 12 min., slight salivation occurred, and continued until death; and in 13 min., the secretion of other buccal glands was increased. No defæcation nor urination occurred.	*With physostigma*, in 2 min., infrequent and slight fibrillary twitches. *After atropia*, in 8 min., distinct paralysis; and in 16 min., general flaccidity, which continued until death, accompanied with feeble tremors and starts. —Rigor began to set in at about 42 min. after death.
186.	*a*	3 lbs. 4 oz. [Experiment *b* was performed fifteen days after experiment *a*.]	0·19	0·054	0·05	Recovery.	*With physostigma*, none. The original size was $\frac{14}{50} \times \frac{13}{50}$. *After atropia*, the size was in 1 min. 30 sec., $\frac{15}{50} \times \frac{15}{50}$; in 4 min., $\frac{18}{50} \times \frac{18}{50}$; in 11 min., $\frac{19}{50} \times \frac{19}{50}$; and in 1 hour 6 min., $\frac{19}{50} \times \frac{19}{50}$. — On the following day, the size was $\frac{18}{50} \times \frac{17}{50}$; on the 3d day, $\frac{16}{50} \times \frac{16}{50}$; and on the 7th day, $\frac{16}{50} \times \frac{15}{50}$.	*With physostigma*, in 3 min., slowing from 39 to 31 per 10 sec. *After atropia*, the rate per 10 sec. was in 3 min., 49. Afterwards, the rate could not be accurately ascertained, on account of frequent fibrillary twitches.—On the following day, it was 34; and on the 3d day, 41.	*With physostigma*, in 3 min. 30 sec., slowing from 35 to 28 per 10 sec. *After atropia*, the rate per 10 sec. was in 11 min., 26; and in 18 min., 28.	*With physostigma*, none noted. *After atropia*, in 2 min., slight increase in the secretion of certain buccal glands, which ceased in about 7 min. No defæcation, urination, nor salivation occurred during the 1 hour and 10 min. of continuous observation.	*With physostigma*, none noted. *After atropia*, in 1 min. 30 sec., extension of the limbs; in 18 min., slight paralysis; and in 1 hour, decided, though not severe, paralysis. No tremors nor spasms occurred. Fibrillary twitches were present in a very well-marked form for more than 1 hour.
	b	3 lbs. 8 oz.	0·14 (= 0·12 gr. p. 3 lbs.)	0	0	Death, in 19 min.	—	—	—	—	—
187.	*a*	3 lbs. 1 oz. [Experiment *b* was performed eleven days after experiment *a*.]	0·183	0·1	0·1	Recovery.	*With physostigma*, none. The original size was $\frac{13}{50} \times \frac{12}{50}$. *After atropia*, the size was in 3 min., $\frac{15}{50} \times \frac{15}{50}$; in 12 min., $\frac{19}{50} \times \frac{19}{50}$; and in 55 min., $\frac{19}{50} \times \frac{19}{50}$.—On the following day, it was $\frac{15}{50} \times \frac{14}{50}$.	*With physostigma*, in 4 min., slowing from 37 to 32 per 10 sec. *After atropia*, the rate per 10 sec. was in 3 min., 49; and in 5 min., 61. Afterwards, the rate could not be ascertained on account of the frequent fibrillary twitches.—On the following day, it was 35.	*With physostigma*, in 3 min. 30 sec., slowing from 24 to 16 per 10 sec. *After atropia*, none noted.	*With physostigma*, none. *After atropia*, in 2 min., slight increase in the secretion of certain buccal glands. There was no defæcation, urination, nor salivation, during the 1 hour and 15 min. of continuous observation.	*With physostigma*, in 2 min., infrequent and slight fibrillary twitches. *After atropia*, the fibrillary twitches soon became very well marked, and continued so for at least 1 hour 10 min. In 8 min., slight paralysis; and in 36 min., well-marked paralysis, which had not perceptibly lessened in 1 hour 15 min. Tremors frequently occurred, and on two occasions feeble general spasms took place.
	b	3 lbs. 2 oz.	0·125 (= 0·12 gr. p. 3 lbs.)	0	0	Death, in 17 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
188. *a* [Experiment *b* was performed eleven days after experiment *a*.]	3 lbs.	0·18	0·2	0·2	Recovery.	*With physostigma*, none. The original size was $\frac{12}{50} \times \frac{11}{50}$. *After atropia*, the size was in 2 min., $\frac{15}{50} \times \frac{15}{50}$; in 7 min., $\frac{18}{50} \times \frac{18}{50}$; in 25 min., $\frac{15}{50} \times \frac{15}{50}$; in 50 min., $\frac{14}{50} \times \frac{14}{50}$; and in 1 hour 50 min., $\frac{12}{50} \times \frac{11}{50}$. —On the following day, it was $\frac{14}{50} \times \frac{13}{50}$.	*With physostigma*, in 4 min. 50 sec., slowing from 41 to 34 per 10 sec. *With atropia*, the rate per 10 sec. was in 5 min., 51; in 11 min., 55; and in 1 hour 50 min., 37.—On the following day, it was 45.	*With physostigma*, none. The original rate was 26 per 10 sec. *With atropia*, the rate per 10 sec. was in 6 min., 24; in 30 min., 20; and in 1 hour 52 min., 18. From 30 min. to 1 hour 18 min., the respirations were considerably impeded by fluid in the fauces and larynx.	*With physostigma*, none noted. *With atropia*, in 3 min., slight increase in the secretion of certain buccal glands, which gradually increased, but which had quite ceased in one hour 20 min. Salivation occurred at 26 min.; and urine was voided at 46 min., and also at 1 hour 18 min. No defæcation occurred during 1 hour and 54 min.	*With physostigma*, in 1 min. 30 sec., infrequent and slight fibrillary twitches. *With atropia*, the fibrillary twitches became well marked, and continued so for at least 1 hour 50 min. In 12 min., distinct paralysis; in 30 min., well-marked paralysis; and in 50 min., only slight paralysis. No distinct tremors occurred.
b	3 lbs.	0·12	0	0	Death, in 24 min.	—	—	—	—	—
189. *a* [Experiment *b* was performed ten days after experiment *a*.]	3lbs. 14½ oz.	0·23	0·39	0·3	Recovery.	*With physostigma*, none. The original size was $\frac{15}{50} \times \frac{15}{50}$. *After atropia*, the size was in 4 min., $\frac{19}{50} \times \frac{19}{50}$; and this size was not changed in 2 hours 40 min.—On the following day, it was $\frac{19}{50} \times \frac{19}{50}$; and on the 8th day, $\frac{17}{50} \times \frac{17}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 44 to 33 per 10 sec. *After atropia*, the rate per 10 sec. was in 5 min., 58; in 1 hour 57; in 1 hour 40 min., 54; and in 2 hours 40 min., 53.—On the following day, the rate per 10 sec. was 37; and on the 3d day, 41.	*With physostigma*, in 4 min., slowing from 35 to 24 per 10 sec. *After atropia*, the rate per 10 sec. was in 35 min, 16; in 1 hour, 26; in 1 hour 40 min., 40; and in 2 hours 40 min., 34.—On the following day the rate per 10 sec. was 17.	*With physostigma*, none. *After atropia*, in 2 min., slight increase in the secretion of certain buccal glands, which ceased in a few minutes. There was no defæcation, urination, nor salivation during the 2 hours and 45 min. of continuous observation.	*With physostigma*, in 2 min., infrequent and slight fibrillary twitches. *After atropia*, the fibrillary twitches became very well marked, and continued so for more than 2 hours 30 min. In 6 min., slight paralysis; in 25 min., well-marked paralysis; and in 1 hour 30 min., only slight paralysis. Tremors frequently occurred, but there were no spasms.
b	4 lbs.	0·16 (= 0.12 gr. p. 3 lbs.)	0	0	Death, in 22 min. 30 sec.	—	—	—	—	—
190. *a* [Experiment *b* was performed nine days after experiment *a*.]	3 lbs. 3 oz.	0·19	0·42	0·4	Recovery.	*With physostigma*, none. The original size was $\frac{13}{50} \times \frac{12}{50}$. *After atropia*, the size was in 6 min., $\frac{16}{50} \times \frac{16}{50}$; in 8 min., $\frac{18}{50} \times \frac{18}{50}$; in 42 min., $\frac{18}{50} \times \frac{19}{50}$; in 1 hour 8 min., $\frac{15}{50} \times \frac{15}{50}$; and in 1 hour 16 min., $\frac{15}{50} \times \frac{15}{50}$.—On the following day, it was $\frac{13}{50} \times \frac{12}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 41 to 37 per 10 sec. *After atropia*, the rate per 10 sec. was in 1 hour 8 min., 57.—On the following day, it was 35.	*With physostigma*, none noted. The original rate was 32 per 10 sec. *After atropia*, the rate per 10 sec. was in 15 min., 28; in 32 min., 27; and in 1 hour, 22.	*With physostigma*, none. *After atropia*, in 55 min., and in 1 hour 8 min., urine was voided. There was neither defæcation nor increase in the secretion of any buccal gland during the 1 hour and 10 min. of continuous observation.	*With physostigma*, in 2 min., infrequent and slight fibrillary twitches. *After atropia*, the fibrillary twitches became very well marked, and continued so for at least 1 hour and 20 min. In 25 min., slight paralysis; in 45 min., well-marked paralysis; and in 1 hour, almost no paralysis. Only slight tremors occurred.
b	3 lbs.	0·12	0	0	Death, in 23 min.	—	—	—	—	—

Number of Experiment.		Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
191.	*a*	2 lbs. 12 oz. [Experiment *b* was performed nine days after experiment *a*.]	0·16	0·45	0·5	Recovery.	*With physostigma*, none. The original size was $\frac{12}{50} \times \frac{11}{50}$. *After atropia*, the size was in 2 min., $\frac{15}{50} \times \frac{15}{50}$; in 8 min., $\frac{10}{50} \times \frac{10}{50}$; in 1 hour, $\frac{15}{50} \times \frac{15}{50}$; and in 1 hour 15 min, $\frac{12}{50} \times \frac{11}{50}$.—On the following day, it was $\frac{12}{50} \times \frac{11}{50}$.	*With physostigma*, in 24 min. 30 sec., slowing from 35 to 26 per 10 sec. *After atropia*, the rate per 10 sec. was in 2 min. 30 sec., 38; in 5 min., 40; and in 10 min., 48.—On the following day, it was 24.	*With physostigma*, in 3 min., slowing from 19 to 13 per 10 sec. *After atropia*, the rate per 10 sec. was in 3 min., 12; and in 10 min., 16.	*With physostigma*, none. *After atropia*, in 3 min., slight increase in the secretion of certain buccal glands, which ceased in a few min. In 1 hour 5 min., several wet fæcal pellets were passed; and in 1 hour 10 min., urine was voided. There was not any salivation.	*With physostigma*, in 2 min., infrequent and slight fibrillary twitches. *After atropia*, the fibrillary twitches soon became well marked, and continued so for at least 1 hour 15 min. In 8 min., slight paralysis; in 35 min., well-marked paralysis; and in 1 hour 15 min., only slight paralysis. Tremors occurred, and twice there were feeble general spasms.
	b	2 lbs. 15 oz.	0·12	0	0	Death, in 25 min.	—	—	—	—	—
192.	*a*	3 lbs. 3 oz. [Experiment *b* performed thirteen days after experiment *a*.]	0·19	0·74	0·7	Recovery.	*With physostigma*, none. The original size was $\frac{11}{50} \times \frac{10}{50}$. *After atropia*, the size was in 5 min., $\frac{15}{50} \times \frac{15}{50}$; in 38 min., $\frac{11}{50} \times \frac{10}{50}$; and in 2 hours 10 min., $\frac{11}{50} \times \frac{10}{50}$.—On the following day, it was $\frac{14}{50} \times \frac{13}{50}$; and on the 5th day, $\frac{13}{50} \times \frac{12}{50}$.	*With physostigma*, in 4 min., slowing from 41 to 30 per 10 sec. *After atropia*, the rate per 10 sec. was not counted until 2 hours 8 min., when it was 50.—On the following day, it was 51; and on the 3d day, 40.	*With physostigma*, in 2 min. 30 sec., slowing from 20 to 18 per 10 sec. *After atropia*, the rate per 10 sec. was not counted until 2 hours, when it was 11. In 2 min., the respirations were often accompanied with moist sounds; in 4 min., constantly so accompanied; and in 20 min., they ceased to be so accompanied.	*With physostigma*, none. *After atropia*, in 1 min., the secretion of certain buccal glands was increased, and this increase continued for about 20 min., but no salivation occurred. In 18 min., a few normal fæcal pellets were passed. No urine was voided during the 2 hours 25 min. of continuous observation.	*With physostigma*, in 1 min. 30 sec., infrequent and slight fibrillary twitches. *After atropia*, the fibrillary twitches soon became well-marked, and continued so for at least 2 hours. In 3 min., slight paralysis; in 18 min., well-marked paralysis; and in 1 hour 20 min., almost no paralysis. Frequently tremors occurred, and on several occasions weak general convulsions took place.
	b	3 lbs. 3 oz.	0·128 (= 0·12 gr. p. 3 lbs.)	0	0	Death, in 22 min.	—	—	—	—	—
193.	*a*	2 lbs. 15 oz. [Experiment *b* was performed thirteen days after experiment *a*.]	0·176	1·18	1·2	Recovery.	*With physostigma*, none. The original size was $\frac{14}{50} \times \frac{13}{50}$. *After atropia*, the size was in 5 min., $\frac{17}{50} \times \frac{17}{50}$.—On the following day, it was $\frac{18}{50} \times \frac{18}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 41 to 33 per 10 sec. *After atropia*, the rate per 10 sec. was in 4 min., 54.—On the following day, it was 44.	*With physostigma*, in 3 min., slowing from 12 to 11 per 10 sec. *After atropia*, none noted.	*With physostigma*, none. *After atropia*, in 9 min., slight increase in the secretion of certain buccal glands, which soon ceased. In 43 min., and in 1 hour 17 min., urine was voided. Neither defæcation nor salivation occurred within 1 hour 30 min.	*With physostigma*, in 1 min. 30 sec., infrequent and slight fibrillary twitches. *After atropia*, the fibrillary twitches soon became well marked, but they had greatly lessened in 1 hour 20 min. In 9 min., slight extension of limbs; in 40 min., distinct paralysis; and in 2 hours 10 min., almost no paralysis. Occasionally tremors took place.
	b	3 lbs.	0·12	0	0	Death, in more than 1 and less than 2 days.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
194. *a* [Experiment *b* was performed sixteen days after experiment *a*.]	4 lbs. 9 oz.	0·27	2·2	1·5	Recovery.	*With physostigma*, none. The original size was $\frac{12}{50} \times \frac{11}{50}$. *After atropia*, the size was in 4 min., $\frac{15}{50} \times \frac{15}{50}$; in 10 min., $\frac{17}{50} \times \frac{17}{50}$; and in 2 hours, $\frac{17}{50} \times \frac{17}{50}$.—On the following day, it was $\frac{17}{50} \times \frac{17}{50}$; and on the 12th day, $\frac{10}{50} \times \frac{9}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 42 to 34 per 10 sec. *After atropia*, the rate per 10 sec. was in 1 min. 30 sec., 44; and in 4 min., 58.—On the following day, it was 55; on the 3d day, 44; and on the 4th day, 41.	*With physostigma*, none. The original rate was 44 per 10 sec. *After atropia*, the rate per 10 sec. was in 20 min., 42; and in 55 min., 43.—On the following day, it was 40.	*With physostigma*, none. *After atropia*, none. Neither defæcation nor urination occurred, nor was there any salivation during the 2 hours of continuous observation.	*With physostigma*, in 2 min., infrequent and slight fibrillary twitches. *After atropia*, the fibrillary twitches became well marked, and continued so for at least 2 hours. In 11 min., slight paralysis; which increased somewhat until 1 hour, and afterwards lessened, so that in 2 hours there was almost no paralysis. Starts occurred after the first 1 hour, and continued during about 40 min.
	b 4 lbs. 4 oz.	0·17 (= 0·12 gr. p. 3 lbs.)	0	0	Death, in 1 hour 10 min.	—	—	—	—	—
195. *a* [Experiment *b* was performed twelve days after experiment *a*.]	3 lbs. 9 oz.	0·21	2·37	2	Recovery.	*With physostigma*, none. The original size was $\frac{14}{50} \times \frac{13}{50}$. *After atropia*, the size was in 2 min., $\frac{18}{50} \times \frac{18}{50}$; and in 1 hour 40 min., $\frac{17}{50} \times \frac{17}{50}$.—On the following day, it was $\frac{17}{50} \times \frac{17}{50}$; and on the 11th day, $\frac{14}{50} \times \frac{13}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 31 to 20 per 10 sec. *After atropia*, the rate per 10 sec. was in 5 min., 56; in 10 min., 62; and in 1 hour 25 min., 57.—On the following day, it was 29; on the 3d day, 30; and on the 11th day, 40.	*With physostigma*, none. The original rate was 18 per 10 sec. *After atropia*, the rate per 10 sec. was in 20 min., 20; in 30 min., 19; in 40 min., 11; and in 1 hour, 16.	*With physostigma*, none. *After atropia*, in 2 min., the secretion of certain buccal glands was slightly increased, but this increase ceased in a few min. In 38 min., urine was freely voided. Neither defæcation nor salivation occurred during the 1 hour and 40 min. of continuous observation.	*With physostigma*, in 2 min., infrequent and slight fibrillary twitches. *After atropia*, the fibrillary twitches soon became well marked, but continued so for only 25 min., and they were very slight and infrequent in 40 min. In 10 min., slight paralysis; in 40 min., well-marked paralysis; and in 1 hour 40 min., distinct but considerably lessened paralysis. Tremors and feeble general spasms occasionaliy took place.
	b 3 lbs. 13 oz.	0·15 (= 0·12 gr. p. 3 lbs.)	0	0	Death, in 16 min.	—	—	—	—	—
196. *a* [Experiment *b* was performed four days after experiment *a*.]	2 lbs. 10 oz.	0·157	1·84	2·1	Recovery.	*With physostigma*, none. The original size was $\frac{11}{50} \times \frac{10}{50}$. *After atropia*, the size was in 8 min., $\frac{15}{50} \times \frac{15}{50}$; and in 3 hours, $\frac{15}{50} \times \frac{15}{50}$.—On the following day, it was $\frac{16}{50} \times \frac{18}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 42 to 34 per 10 sec. *After atropia*, the rate per 10 sec. was in 3 min., 52; in 6 min., 58; in 17 min., 53; in 55 min., 49; and in 3 hours, 55.—On the following day, it was 34; and on the 3d day, 39.	*With physostigma*, none. The original rate was 22 per 10 sec. *After atropia*, the rate per 10 sec. was in 4 min., 29; in 17 min., 34; in 30 min., 29; and in 3 hours, 21.	*With physostigma*, in 4 min. 40 sec., slight increase in the secretion of certain buccal glands. *After atropia*, none. There was no defæcation, urination, nor salivation during the 3 hours of continuous observation.	*With physostigma*, in 2 min., infrequent and slight fibrillary twitches. *After atropia*, the fibrillary twitches soon became well marked, but they again became slight in 3 hours. In 7 min., there was some extension of the limbs; in 10 min., distinct paralysis; in 30 min., pretty well-marked paralysis; and in 3 hours, slight paralysis. Occasionally, very feeble tremors occurred.
	b 2 lbs. 7 oz.	0·097 (= 0·12 gr. p. 3 lbs.)	0	0	Death, in 22 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
197. *a*	2 lbs. 15 oz. [Experiment *b* was performed seven days after experiment *a*.]	0·17	2·05	2·1	Recovery.	*With physostigma*, in 4 min., dilatation from $\frac{11}{50} \times \frac{10}{50}$ to $\frac{12}{50} \times \frac{11}{50}$. *After atropia*, the size was in 5 min., $\frac{17}{50} \times \frac{17}{50}$; and in 1 hour 15 min., $\frac{18}{50} \times \frac{18}{50}$.—On the following day, it was $\frac{18}{50} \times \frac{18}{50}$; on the 4th day, $\frac{14}{50} \times \frac{13}{50}$; and on the 5th day, $\frac{11}{50} \times \frac{10}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 36 to 29 per 10 sec. *After atropia*, the rate per 10 sec. was in 3 min., 51; in 7 min., 63; and in 1 hour 26 min., 62.—On the following day, it was 27; and on the 4th day, 43.	*With physostigma*, none. The original rate was 11 per 10 sec. *After atropia*, the rate per 10 sec. was in 3 min., 9; in 4 min., 11; in 10 min., 16; in 30 min., 13; and in 1 hour 14 min., 10.	*With physostigma*, in 3 min., slight increase in the secretion of certain buccal glands. *After atropia*, none. There was no defæcation, urination, nor salivation during the 1 hour 30 min. of continuous observation.	*With physostigma*, in 2 min., infrequent and slight fibrillary twitches. *After atropia*, the fibrillary twitches soon became pretty well marked, but they again became very slight after 20 min. In 10 min., distinct paralysis; in 35 min., well-marked and advanced paralysis; and in 1 hour 30 min., pretty well-marked paralysis. Occasionally tremors and feeble convulsions took place.
b	2 lbs. 15 oz.	0·117 (= 0·12 gr. p. 3 lbs.)	0	0	Death, in 30 min.	—	—	—	—	—
198. *a*	3 lbs. 8 oz. [Experiment *b* was performed eight days after experiment *a*.]	0·21	2·5	2·2	Recovery.	*With physostigma*, none. The original size was $\frac{14}{50} \times \frac{13}{50}$. *After atropia*, the size was in 5 min., $\frac{17}{50} \times \frac{17}{50}$; and in 1 hour 20 min., $\frac{18}{50} \times \frac{18}{50}$.—On the following day, it was $\frac{20}{50} \times \frac{20}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 42 to 31 per 10 sec. *After atropia*, the rate per 10 sec. was in 12 min., 49; in 40 min., 42; and in 1 hour 15 min., 35.—On the following day, it was 26; and on the 3d day, 39.	*With physostigma*, none. The original rate was 15 per 10 sec. *After atropia*, the rate per 10 sec. was in 12 min., 24; in 40 min., 12; in 50 min., 10; and in 1 hour 20 min., 12. —On the following day, it was 11.	*With physostigma*, none. *After atropia*, none. There was no defæcation, urination, nor salivation during the 1 hour and 30 min. of continuous observation.	*With physostigma*, in 2 min., infrequent and slight fibrillary twitches. *After atropia*, the fibrillary twitches were pretty well marked for 35 min., but afterwards they were only slight. In 10 min., distinct paralysis; and in 20 min., pretty well-marked paralysis, which had not lessened much in 1 hour 20 min. Occasionally feeble tremors occurred.
b	3 lbs. 7 oz.	0·14 (= 0.12 gr. p. 3 lbs.)	0	0	Death, in 19 min.	—	—	—	—	—
199.	2 lbs. 14 oz.	0·17	2·1	2·2	Death, in 22 min. after the administration of physostigma.	*With physostigma*, in 3 min. 30 sec., dilatation from $\frac{13}{50} \times \frac{12}{50}$ to $\frac{14}{50} \times \frac{13}{50}$. *After atropia*, the size was in 2 min., $\frac{17}{50} \times \frac{17}{50}$; and in 16 min. 30 sec., $\frac{18}{50} \times \frac{18}{50}$.—After death, it was in 2 min., $\frac{14}{50} \times \frac{14}{50}$; in 14 min., $\frac{11}{50} \times \frac{10}{50}$; in 16 min., $\frac{13}{50} \times \frac{13}{50}$; and in 50 min., $\frac{14}{50} \times \frac{13}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 38 to 29 per 10 sec. *After atropia*, the rate per 10 sec. was in 4 min., 57; and in 12 min., 68.	*With physostigma*, in 3 min., slowing from 13 to 10 per 10 sec. *After atropia*, the rate per 10 sec. was in 5 min., 15. In 13 min., infrequent gasps occurred, and continued until death.	*With physostigma*, none. *After atropia*, in 1 min., slight increase took place in the secretion of certain buccal glands, which ceased in a few minutes. There was not any defæcation, urination, or salivation.	*With physostigma*, in 2 min., infrequent and slight fibrillary twitches. *After atropia*, the fibrillary twitches became pretty well marked; but had nearly ceased in 15 min. In 10 min., distinct paralysis; and in 14 min., well-marked paralysis. Tremors and spasms occurred. —Rigor began to set in at 1 hour 16 min. after death (temp. of laboratory, 64° F.).

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
200.	3 lbs. 5 oz.	0·19	2·5	2·3	Death, in 1 hour 1 min. after the administration of physostigma.	*With physostigma*, in 3 min., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{15}{50} \times \frac{15}{50}$. *After atropia*, the size was in 3 min., $\frac{19}{50} \times \frac{19}{50}$; and this size remained until death.—After death, the size was in 5 min., $\frac{18}{50} \times \frac{18}{50}$; in 9 min., $\frac{15}{50} \times \frac{15}{50}$; in 24 min., $\frac{12}{50} \times \frac{12}{50}$; in 37 min., $\frac{14}{50} \times \frac{14}{50}$; and in 55 min., $\frac{15}{50} \times \frac{15}{50}$.	*With physostigma*, in 4 min. 20 sec., slowing from 40 to 31 per 10 sec. *After atropia*, the rate per 10 sec. was in 2 min., 54; in 30 min., 38; in 40 min., 37; in 50 min., 27; and in 55 min., 24.	*With physostigma*, in 3 min. 30 sec., acceleration from 18 to 20 per 10 sec. *After atropia*, the rate per 10 sec. was in 6 min., 23; in 25 min., 18; in 38 min., 8; and in 47 min., 6. The respirations were now very shallow and non-rhythmical, and they continued so until death.	*With physostigma*, none. *After atropia*, in 38 min., urine was voided. There was no defæcation, salivation, nor evidence of increase in the secretion of any buccal gland.	*With physostigma*, in 1 min. 30 sec., infrequent and slight fibrillary twitches. *After atropia*, the twitches became pretty well marked, but soon they were only slight, and they disappeared before death. In 14 min., distinct paralysis; and in 40 min., general flaccidity, which continued until death. Frequently weak tremors and starts occurred.—Rigor first began to set in at 1 hour 5 min. after death (temp. of laboratory, 58° F.).
201.	3 lbs. 2 oz.	0·187	2·5	2·4	Death, in 48 min. after the administration of physostigma.	*With physostigma*, none. The original size was $\frac{15}{50} \times \frac{15}{50}$. *After atropia*, the size was in 3 min., $\frac{17}{50} \times \frac{17}{50}$; and in 42 min. 30 sec., $\frac{17}{50} \times \frac{17}{50}$.—After death, it was in 2 min., $\frac{16}{50} \times \frac{16}{50}$; in 9 min., $\frac{11}{50} \times \frac{11}{50}$; and in 50 min., $\frac{12}{50} \times \frac{12}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 43 to 30 per 10 sec. *After atropia*, the rate per 10 sec. was in 2 min., 53; in 20 min., 63; and in 42 min., 58.	*With physostigma*, in 3 min., acceleration from 23 to 26 per 10 sec. *After atropia*, the rate per 10 sec. was in 3 min., 26; in 11 min., 36; in 27 min., 20; and in 37 min., 8. Afterwards, mere gasps occurred infrequently until death.	*With physostigma*, none. *After atropia*, in 37 min., urine was voided. There was neither defæcation nor salivation.	*With physostigma*, in 1 min. 20 sec., infrequent and slight fibrillary twitches. *After atropia*, the fibrillary twitches became pretty well marked, but they altogether ceased in 19 min. In 9 min., slight paralysis; and in 30 min., general flaccidity. Frequently weak tremors and starts occurred.—Rigor first began to set in at 25 min. after death (temp. of laboratory, 61° F.).
202.	2 lbs. 15 oz.	0·176	2·35	2·4	Death, in 54 min. after the administration of physostigma.	*With physostigma*, none. The original size was $\frac{10}{50} \times \frac{9}{50}$. *After atropia*, the size was in 1 min. 30 sec., $\frac{14}{50} \times \frac{14}{50}$; in 3 min., $\frac{15}{50} \times \frac{15}{50}$; and in 44 min., $\frac{15}{50} \times \frac{14}{50}$.—After death, it was in 2 min., $\frac{14}{50} \times \frac{14}{50}$; in 7 min., $\frac{13}{50} \times \frac{13}{50}$; and in 1 hour 6 min., $\frac{13}{50} \times \frac{13}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 42 to 31 per 10 sec. *After atropia*, the rate per 10 sec. was in 2 min., 49; in 16 min., 60; in 25 min., 54; in 33 min., 37; and in 47 min., 20 (feeble).	*With physostigma*, none. The original rate was 36 per 10 sec. *After atropia*, the rate per 10 sec. was in 3 min., 39; in 15 min., 33; in 24 min., 13; and in 29 min., 4. Afterwards, only feeble gasps occurred irregularly until death.	*With phyostigma*, none. *After atropia*, none. There was no defæcation, urination, nor salivation.	*With physostigma*, in 1 min. 30 sec., infrequent and slight fibrillary twitches. *After atropia*, the fibrillary twitches soon became well-marked, but they altogether ceased before death. In 16 min., slight paralysis; and in 23 min., general flaccidity. Frequently, tremors and weak spasms occurred.—There was no appearance of rigor at 1 hour 6 min. after death (temp. of laboratory, 61° F.).

Number of Experiment.	Weight of Rabbit.	sostigma (in Grains). Actual Dose of Sul. of Physostigmia.	plate of Atropia (in Grains). Actual Dose.	Dose p. 3 lbs. of Animal.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
203.	3 lbs.	0·18	2·5	2·5	Death, in 1 hour 14 min. after the administration of physostigma.	*With physostigma*, none. The original size was $\frac{12}{50} \times \frac{11}{50}$. *After atropia*, the size was in 2 min., $\frac{17}{50} \times \frac{17}{50}$; in 8 min., $\frac{18}{50} \times \frac{18}{50}$; in 1 hour 3 min., $\frac{19}{50} \times \frac{19}{50}$; and in 1 hour 8 min., $\frac{19}{50} \times \frac{19}{50}$. — After death, it was in 1 min., $\frac{16}{50} \times \frac{16}{50}$; in 3 min., $\frac{14}{50} \times \frac{14}{50}$; and in 11 min., $\frac{10}{50} \times \frac{9}{50}$.	*With physostigma*, in 4 min., slowing from 44 to 38 per 10 sec. *After atropia*, the rate per 10 sec. was in 5 min., 53; in 50 min., 46; in 1 hour, 37; and in 1 hour 7 min., 23.	*With physostigma*, none. The original rate was 26 per 10 sec. *After atropia*, the rate per 10 sec. was in 12 min., 38; in 26 min., 23; in 34 min., 15; in 49 min., 12; and in 1 hour, 4. Afterwards, mere gasps occurred infrequently and irregularly until death.	*With physostigma*, none. *After atropia*, none. There was no defæcation, urination, nor salivation; nor any evidence of increase in the secretion of any buccal gland.	*With physostigma*, in 2 min., infrequent and slight fibrillary twitches. *After atropia*, the fibrillary twitches became pretty well marked, but they had altogether disappeared at 50 min. In 2 min., stiff extension of the limbs occurred; in 15 min., well-marked paralysis was present; and in 1 hour, general flaccidity. Frequently, tremors and weak spasms occurred. —Rigor first began to set in at 28 min. after death (temp. of laboratory, 62° F.).
204.	3 lbs. 1 oz.	0·183	3·06	3	Death, in 52 min. after the administration of physostigma.	*With physostigma*, none. The original size was $\frac{12}{50} \times \frac{11}{50}$. *After atropia*, the size was in 3 min., $\frac{17}{50} \times \frac{17}{50}$; in 30 min., $\frac{15}{50} \times \frac{15}{50}$; and in 45 min., $\frac{15}{50} \times \frac{15}{50}$. — After death, it was in 1 min., $\frac{14}{50} \times \frac{14}{50}$; in 15 min., $\frac{10}{50} \times \frac{9}{50}$; and in 1 hour 14 min., $\frac{12}{50} \times \frac{11}{50}$.	*With physostigma*, in 4 min., slowing from 43 to 36 per 10 sec. *After atropia*, the rate per 10 sec. was in 4 min., 56; in 38 min., 52; in 43 min., 50; and in 45 min., 42.	*With physostigma*, in 3 min., slowing from 38 to 35 per 10 sec. *After atropia*, the rate per 10 sec. was in 3 min., 34; in 16 min., 32; in 21 min., 16; in 27 min., 11; and in 39 min., 8. Soon afterwards, only gasps occurred until death.	*With physostigma*, none. *After atropia*, none. There was no defæcation, urination, nor salivation.	*With physostigma*, in 2 min., infrequent and slight fibrillary twitches. *After atropia*, the fibrillary twitches became pretty well marked, but soon they altogether ceased. In 13 min., slight paralysis; and in 38 min., general flaccidity. Frequently, tremors and weak spasms occurred.—Rigor first began to set in at about 30 min. after death (temp. of laboratory, 54° F.).

TABLE 4.—EXPERIMENTS WITH TWICE THE MINIMUM-LETHAL DOSE OF PHYSOSTIGMA (0·24 *gr. of Sulphate of Physostigmia per Three Pounds Weight of Rabbit*).

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
205.	3 lbs. 4 oz.	0·26	0·05	0·05	Death, in 46 min. after the administration of physostigma.	*With physostigma*, none. The original size was $\frac{13}{50} \times \frac{12}{50}$. *After atropia*, the size was in 14 min., $\frac{18}{50} \times \frac{13}{50}$; and in 40 min., $\frac{18}{50} \times \frac{18}{50}$. —After death, the size was in 1 min., $\frac{16}{50} \times \frac{16}{50}$; in 1 min. 30 sec., $\frac{12}{50} \times \frac{12}{50}$; in 4 min., $\frac{6}{50} \times \frac{6}{50}$; and in 55 min., $\frac{10}{50} \times \frac{10}{50}$.	*With physostigma*, in 4 min., slowing from 40 to 35 per 10 sec. *After atropia*, the rate per 10 sec. was in 30 min., 41; and in 34 min., 30.	*With physostigma*, none. The original rate was 30 per 10 sec. *After atropia*, the rate per 10 sec. was in 17 min., 36; in 31 min., 8; in 35 min., 6; and in 37 min., 12. Afterwards, only gasps occurred. The respirations were accompanied with moist sounds until about 12 min. before death.	*With physostigma*, none. *After atropia*, in 6 min., the secretion of certain buccal glands was increased, and soon afterwards salivation occurred; and this increase continued until 15 min. before death. There was neither defæcation nor urination.	*With physostigma*, in 3 min., infrequent and slight fibrillary twitches. *After atropia*, the fibrillary twitches soon became very well marked, but they lessened considerably shortly before death. In 6 min., slight paralysis; and in 27 min., general flaccidity. Frequently, tremors occurred. —Rigor first began to set in at about 50 min. after death (temp. of laboratory, 58° F.).
206.	3 lbs.	0·24	0·08	0·08	Death, in about 50 min. after the administration of physostigma.	*With physostigma*, in 4 min., dilatation from $\frac{9}{50} \times \frac{8}{50}$ to $\frac{10}{50} \times \frac{9}{50}$. *After atropia*, the size was in 3 min., $\frac{15}{50} \times \frac{15}{50}$; in 5 min., $\frac{17}{50} \times \frac{18}{50}$; and in 15 min., $\frac{16}{50} \times \frac{16}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 40 to 30 per 10 sec. *After atropia*, the rate per 10 sec. was in 4 min., 48; and in 17 min., 56.	*With physostigma*, in 3 min., slowing from 16 to 14 per 10 sec. *After atropia*, the rate per 10 sec. was in 6 min., 20; in 15 min., 16; and in 42 min., 5.	*With physostigma*, none. *After atropia*, in 1 min., slight increase in the secretion of certain buccal glands, which ceased in about 4 min. There was no defæcation, urination, nor salivation.	*With physostigma*, in 2 min., infrequent and slight fibrillary twitches. *After atropia*, the fibrillary twitches soon became well marked. In 5 min., some extension of the limbs took place; in 8 min., there was slight paralysis; and in 29 min., general flaccidity. Tremors frequently occurred.
207.	3 lbs. 8 oz.	0·28	0·093	0·08	Death, in 51 min. after the administration of physostigma.	*With physostigma*, in 2 min. 30 sec., dilatation from $\frac{13}{50} \times \frac{12}{50}$ to $\frac{14}{50} \times \frac{13}{50}$. *After atropia*, the size was in 6 min., $\frac{16}{50} \times \frac{16}{50}$; in 12 min., $\frac{17}{50} \times \frac{16}{50}$; in 37 min., $\frac{11}{50} \times \frac{10}{50}$; and in 45 min., $\frac{14}{50} \times \frac{13}{50}$. —After death, it was in 1 min., $\frac{12}{50} \times \frac{11}{50}$; and in 3 min., $\frac{10}{50} \times \frac{10}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 42 to 37 per 10 sec. *After atropia*, the rate per 10 sec. was in 3 min., 26; in 6 min., 43; in 11 min., 56; and in 41 min., 21.	*With physostigma*, none. The original rate was 21 per 10 sec. *After atropia*, the rate per 10 sec. was in 11 min., 24; and in 37 min., 5. Afterwards, gasps only occurred. In 20 min., respiration was impeded by mucus in the fauces, and continued to be so impeded until death.	*With physostigma*, none. *After atropia*, in 4 min., slight increase occurred in the secretion of certain buccal glands, which soon became greater, and continued until death. There was salivation and defæcation, but no urination.	*With physostigma*, in 1 min., infrequent and slight fibrillary twitches. *After atropia*, the fibrillary twitches soon became well marked, and continued so until death. In 6 min., the limbs were extended; in 11 min., there was slight paralysis; and in 27 min., general flaccidity. Frequently, tremors and weak general spasms took place.—There was no rigor at 36 min. after death (temp. of laboratory, 62° F.).
208.	3 lbs. 4½ oz.	0·26	0·1	0·09	Death, in 30 min. after the administration of physostigma.	*With physostigma*, none. The original size was $\frac{10}{50} \times \frac{11}{50}$. *After atropia*, the size was in 8 min., $\frac{10}{50} \times \frac{10}{50}$; in 15 min., $\frac{8}{50} \times \frac{7}{50}$; and in 22 min., $\frac{4}{50} \times \frac{3}{50}$.— After death, the size was in 3 min., $\frac{5}{50} \times \frac{4}{50}$; and in 50 min., $\frac{6}{50} \times \frac{5}{50}$.	*With physostigma*, in 4 min., slowing from 38 to 35 per 10 sec. *After atropia*, the rate could not be accurately determined on account of fibrillary twitches and restlessness, but the impulse was weak, and occurred infrequently, so often as it was examined.	*With physostigma*, none. The original rate was 10 per 10 sec. *After atropia*, the rate per 10 sec. was in 22 min., 4; and afterwards only weak gasps occurred. In 12 min., the respirations were noisy; they soon became much impeded by mucus, and continued to be so until death.	*With physostigma*, none. *After atropia*, in 3 min., slight increase in the secretion of certain buccal glands, which soon became greater, and continued until death. In 22 min., several normal fæcal pellets were passed; but there was no urination.	*With physostigma*, in 1 min., infrequent and slight fibrillary twitches. *After atropia*, the fibrillary twitches soon became well marked, and continued so until death. In 5 min., there was some extension of the limbs; in 8 min., slight paralysis; and in 20 min., general flaccidity. Tremors frequently occurred.—Rigor first began to set in at about 50

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
209. *a*	3 lbs. 12 oz. [Experiment *b* was performed fourteen days after experiment *a*.]	0·3	0·12	0·1	Recovery.	*With physostigma*, none. The original size was $\frac{10}{50} \times \frac{9}{50}$. *After atropia*, the size was in 9 min., $\frac{16}{50} \times \frac{16}{50}$; in 1 hour 20 min., $\frac{16}{50} \times \frac{16}{50}$; and in 2 hours 5 min., $\frac{16}{50} \times \frac{16}{50}$.—On the following day, it was $\frac{14}{50} \times \frac{14}{50}$; and on the 4th day, $\frac{11}{50} \times \frac{10}{50}$.	*With physostigma*, in 4 min., slowing from 40 to 33 per 10 sec. *After atropia*, the rate per 10 sec. was in 1 hour 22 min., 46; and in 2 hours, also 46.—On the following day, it was 31; and on the 4th day, 35.	*With physostigma*, in 4 min. 10 sec., acceleration from 29 to 33 per 10 sec. *After atropia*, the rate per 10 sec. was in 45 min., 22; and in 2 hours 10 min., 15.	*With physostigma*, none. *After atropia*, in 2 hours, a few normal fæcal pellets were passed. There was no defæcation, salivation, nor evidence of increase in the secretion of any buccal gland.	*With physostigma*, in 2 min., infrequent and slight fibrillary twitches. *After atropia*, the fibrillary twitches soon became very well marked, and continued so for at least 2 hours. In 9 min., slight paralysis; in 44 min., well-marked paralysis; and in 2 hours 10 min, almost no paralysis. Tremors and starts frequently occurred.
b	3 lbs. 11 oz.	0·22 (= about 0·18 gr. p. 3 lbs.)	0	0	Death, in 12 min.	—	—	—	—	—
210. *a*	3 lbs. 1 oz. [Experiment *b* was performed nine days after experiment *a*.]	0·245	0·2	0·2	Recovery.	*With physostigma*, none. The original size was $\frac{11}{50} \times \frac{10}{50}$. *After atropia*, the size was in 2 min., $\frac{8}{50} \times \frac{7}{50}$; in 5 min., $\frac{14}{50} \times \frac{14}{50}$; in 7 min., $\frac{10}{50} \times \frac{10}{50}$; and in 1 hour, $\frac{16}{50} \times \frac{16}{50}$.—On the following day, it was $\frac{13}{50} \times \frac{12}{50}$; and on the 6th day, $\frac{11}{50} \times \frac{10}{50}$.	*With physostigma*, none noted. The original rate was 40 per 10 sec. *After atropia*, the rate per 10 sec. was not noted until the following day, when it was 30.	*With physostigma*, none. The original rate was 21 per 10 sec. *After atropia*, the rate was not noted.	*With physostigma*, none. *After atropia*, in 2 min., increase in the secretion of certain buccal glands, sufficient to cause moist sounds with respiration; but this ceased in 3 min. There was no salivation, defæcation, nor urination.	*With physostigma*, in 1 min. 30 sec., infrequent and slight fibrillary twitches; and in 4 min. 30 sec., confused stumbling movements. *After atropia*, the fibrillary twitches soon became well marked, and continued so for at least 1 hour. In 7 min., slight paralysis; in 16 min., well-marked paralysis; and in 1 hour 15 min., also well-marked paralysis. Frequently tremors and starts occurred.
b	3 lbs. 2 oz.	0·127 (= 0·12 gr. p. 3 lbs.)	0	0	Death, in 15 min.	—	—	—	—	—
211. *a*	3 lbs. $2\frac{1}{2}$ oz. [Experiment *b* was performed ten days after experiment *a*.]	0·25	0·31	0·3	Recovery.	*With physostigma*, none. The original size was $\frac{13}{50} \times \frac{13}{50}$. *After atropia*, the size was in 4 min., $\frac{18}{50} \times \frac{18}{50}$; in 50 min., $\frac{10}{50} \times \frac{10}{50}$; and in 1 hour, $\frac{19}{50} \times \frac{19}{50}$.—On the following day, it was $\frac{16}{50} \times \frac{16}{50}$; and on the 4th day, $\frac{14}{50} \times \frac{13}{50}$.	*With physostigma*, none noted. The original rate was 36 per 10 sec. *After atropia*, the rate per 10 sec. could not be accurately determined because of the fibrillary twitches, until 1 hour 20 min., when it was 40.—On the following day, it was 47; and on the 4th day, 43.	*With physostigma*, in 3 min., acceleration from 24 to 26 per 10 sec. *After atropia*, the rate per 10 was in 1 hour 20 min., 25.	*With physostigma*, in 4 min., slight increase in the secretion of certain buccal glands. *After atropia*, none. There was no defæcation, urination, nor salivation during the 1 hour and 20 min. of continuous observation.	*With physostigma*, in 2 min., slight fibrillary twitches; and in 4 min. 30 sec., unsteadiness. *After atropia*, the fibrillary twitches soon became very well marked, and continued so for at least 1 hour. In 18 min., slight paralysis; in 26 min., well-marked paralysis; and in 1 hour 20 min., marked, though lessened, paralysis. Tremors and feeble general spasms frequently occurred.
b	3 lbs. $3\frac{1}{2}$ oz.	0.128 (= 0·12 gr. p. 3 lbs.)	0	0	Death, in 27 min.	—	—	—	—	—

Number of Experiment.		Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
212.	*a*	3 lbs. 5 oz. [Experiment *b* was performed twelve days after experiment *a*.]	0·26	0·43	0·4	Recovery.	*With physostigma*, in 4 min., dilatation from $\frac{14}{50}\times\frac{13}{50}$ to $\frac{15}{50}\times\frac{14}{50}$. *After atropia*, the size was in 3 min., $\frac{17}{50}\times\frac{17}{50}$; and in 1 hour, about $\frac{20}{50}\times\frac{20}{50}$.—On the following day, it was $\frac{20}{50}\times\frac{20}{50}$; on the 7th day, $\frac{19}{50}\times\frac{19}{50}$; and on the 10th day, $\frac{16}{50}\times\frac{15}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 39 to 37 per 10 sec. *After atropia*, the rate per 10 sec. was in 4 min., 56; in 15 min., 58; and in 50 min., 50.—On the following day, it was 34; on the 3d day, 33; on the 4th day, 48; and on the 7th day, 41.	*With physostigma*, in 3 min. 30 sec., acceleration from 20 to 31 per 10 sec. *After atropia*, the rate per 10 sec. was in 15 min., 31; and in 48 min., 21.	*With physostigma*, none noted. *After atropia*, in 2 min., slight increase in the secretion of certain buccal glands, which ceased in a few min. There was no defæcation, urination, nor salivation during the 1 hour of continuous observation.	*With physostigma*, in 2 min. 30 sec., slight fibrillary twitches. *After atropia*, the fibrillary twitches became well marked, and continued so for at least 1 hour. In 8 min., slight paralysis; and in 15 min., well-marked paralysis, which had not appreciably lessened in 1 hour. Occasionally weak tremors and starts took place.
	b	3 lbs. 6 oz.	0·13 (= 0·12 gr. p. 3 lbs.)	0	0	Death, in 16 min.	—	—	—	—	—
213.	*a*	3 lbs. [Experiment *b* was performed eighteen days after experiment *a*.]	0·24	0·5	0·5	Recovery.	*With physostigma*, in 4 min., dilatation from $\frac{9}{50}\times\frac{8}{50}$ to $\frac{10}{50}\times\frac{9}{50}$. *After atropia*, the size was in 6 min., $\frac{16}{50}\times\frac{16}{50}$; in 35 min., $\frac{15}{50}\times\frac{15}{50}$; in 58 min., $\frac{12}{50}\times\frac{11}{50}$; and in 1 hour 40 min., $\frac{10}{50}\times\frac{9}{50}$.—On the following day, it was $\frac{10}{50}\times\frac{9}{50}$; and on the 3d day, $\frac{8}{50}\times\frac{7}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 40 to 34 per 10 sec. *After atropia*, the rate per 10 sec. was in 5 min., 50. Further observations were not possible on account of the well-marked fibrillary twitches.—On the following day, the rate per 10 sec. was 36; and on the 3d day, 41.	*With physostigma*, in 3 min., slowing from 24 to 20 per 10 sec. *After atropia*, the rate per 10 sec. was in 43 min., 19; and in 1 hour 20 min., 18.	*With physostigma*, none. *After atropia*, in 25 min. and in 55 min., urine was voided. In 1 hour 30 min. and in 1 hour 50 min., a number of wet fæcal pellets were passed. There was not any obvious increase in the secretion of the buccal glands.	*With physostigma*, in 1 min. 30 sec., infrequent and slight fibrillary twitches. *After atropia*, the fibrillary twitches soon became very well marked, and continued so for at least 1 hour 50 min. In 9 min., slight paralysis; in 25 min., well-marked paralysis; and in 1 hour 55 min., only slight paralysis. Frequently tremors and starts occurred.
	b	3 lbs. 3½ oz.	0·125 (= 0·12 gr. p. 3 lbs.)	0	0	Death, in 23 min.	—	—	—	—	—
214.	*a*	3 lbs. [Experiment *b* was performed ten days after experiment *a*.]	0·24	0·5	0·5	Recovery.	*With physostigma*, none noted. The original size was $\frac{12}{50}\times\frac{11}{50}$. *After atropia*, the size was in 5 min., $\frac{16}{50}\times\frac{16}{50}$; in 11 min., $\frac{17}{50}\times\frac{17}{50}$; and in 2 hours, $\frac{17}{50}\times\frac{17}{50}$.—On the following day, it was $\frac{17}{50}\times\frac{17}{50}$; on the 3d day, $\frac{16}{50}\times\frac{16}{50}$; and on the 10th day, $\frac{13}{50}\times\frac{12}{50}$.	*With physostigma*, none noted. The original rate was 42 per 10 sec. *After atropia*, none noted until 1 hour 40 min., when the rate per sec. was 41.—On the following day also, it was 41.	*With physostigma*, in 4 min., slowing from 22 to 19 per 10 sec. *After atropia*, the rate per 10 sec. was in 8 min., 23; in 15 min., 20; in 55 min., 19; and in 1 hour 21 min., 16.—On the following day, it was 30, and irregular.	*With physostigma*, none. *After atropia*, in 1 min., there was slight increase in the secretion of certain buccal glands, which ceased in a few min. In 1 hour 3 min., a few normal fæcal pellets were passed. There was no urination nor salivation during the 2 hours 5 min. of continuous observation.	*With physostigma*, in 2 min. 30 sec., infrequent and slight fibrillary twitches. *After atropia*, the fibrillary twitches soon became well marked, but they had altogether ceased at 55 min. In 5 min., slight paralysis; in 7 min., well-marked paralysis, which continued for about 1 hour 30 min.; and in 2 hours 5 min., decided, though lessened, paralysis. Occasionally slight tremors occurred.
	b	2 lbs. 15 oz.	0·117 (= 0·12 gr. p. 3 lbs.)	0	0	Death, in 29 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
215. *a*	3 lbs. 3 oz. [Experiment *b* was performed six days after experiment *a*.]	0·25	0·83	0·8	Recovery.	*With physostigma*, none. The original size was $\frac{12}{50} \times \frac{11}{50}$. *After atropia*, the size was in 3 min., $\frac{16}{50} \times \frac{16}{50}$; in 8 min., $\frac{17}{50} \times \frac{17}{50}$; and in 45 min., $\frac{18}{50} \times \frac{18}{50}$.—On the following day, it was $\frac{16}{50} \times \frac{16}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 41 to 31 per 10 sec. *After atropia*, the rate per 10 sec. was in 5 min., 58; in 11 min., 52; and in 34 min., 40.—On the following day, it was 40.	*With physostigma*, none. The original rate was 14 per 10 sec. *After atropia*, in 46 min., the rate was 14 per 10 sec.	*With physostigma*, none. *After atropia*, in 2 min., slight increase in the secretion of certain buccal glands. No salivation, defæcation, nor urination occurred during the 50 min. of continuous observation.	*With physostigma*, in 2 min., infrequent and slight fibrillary twitches. *After atropia*, the fibrillary twitches became pretty well marked. In 5 min., slight paralysis; and in 5 min., decided though not great paralysis.
b	3 lbs. 2 oz.	0·125 (= 0·12 gr. p. 3 lbs.)	0	0	Death, in 19 min.	—	—	—	—	—
216. *a*	2 lbs. 12 oz. [Experiment *b* was performed eleven days after experiment *a*.]	0·22	0·8	0·9	Recovery.	*With physostigma*, none. The original size was $\frac{11}{50} \times \frac{10}{50}$. *After atropia*, the size was in 5 min., $\frac{15}{50} \times \frac{15}{50}$; in 24 min., $\frac{16}{50} \times \frac{16}{50}$; in 2 hours, $\frac{12}{50} \times \frac{11}{50}$; and in 3 hours 30 min., $\frac{12}{50} \times \frac{11}{50}$.—On the following day, it was $\frac{15}{50} \times \frac{15}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 37 to 31 per 10 sec. *After atropia*, the rate per 10 sec. was in 7 min., about 52; in 2 hours, 48; and in 3 hours 31 min., 34.—On the following day, it was 23.	*With physostigma*, in 3 min. 30 sec., slowing from 26 to 23 per 10 sec. *After atropia*, the rate per 10 sec. was in 2 min., 28; in 20 min., 16; in 2 hours, 14; and in 3 hours 29 min., 12.	*With physostigma*, none. *After atropia*, in 3 min., slight increase in the secretion of certain buccal glands, which ceased in a few minutes. In 2 hours, urine was voided; and in 2 hours 30 min., several soft fæcal pellets were passed.	*With physostigma*, in 1 min. 30 sec., infrequent and slight fibrillary twitches. *After atropia*, the fibrillary twitches soon became very well marked, but they had lessened considerably in 2 hours. In 6 min., stiff extension of the fore limbs; in 12 min., slight paralysis; in 20 min., well-marked paralysis; and in 3 hours only slight paralysis. Tremors frequently occurred.
b	2 lbs. 14 oz.	0·115 (= 0·12 gr. p. 3 lbs.)	0	0	Death, in 24 min.	—	—	—	—	—
217. *a*	3 lbs. 10 oz. [Experiment *b* was performed twelve days after experiment *a*.]	0·29	1·2	1·	Recovery.	*With physostigma*, none. The original size was $\frac{15}{50} \times \frac{15}{50}$. *After atropia*, the size was in 13 min., $\frac{19}{50} \times \frac{19}{50}$; and this remained for at least 1 hour 45 min. —On the following day, the size was $\frac{19}{50} \times \frac{19}{50}$; and on the 5th day, $\frac{18}{50} \times \frac{18}{50}$.	*With physostigma*, in 4 min., slowing from 41 to 35 per 10 sec. *After atropia*, the rate per 10 sec. was in 7 min., 50; and in 36 min., 52.—On the following day, it was 46; on the 4th day, 43; on the 5th day, 39; and on the 6th day, 41.	*With physostigma*, in 3 min., acceleration from 21 to 31 per 10 sec. *After atropia*, the rate per 10 sec. was in 18 min., 29; in 33 min., 14; in 43 min., 12; and in 1 hour 20 min., 12.—On the following day it was 19.	*With physostigma*, none. *After atropia*, none. There was no salivation, defæcation, nor urination during the 1 hour 50 min. of continuous observation.	*With physostigma*, slight fibrillary twitches and unsteadiness. *After atropia*, the fibrillary twitches soon became well marked, but in 30 min. they were only slight, while in 1 hour 43 min. they had altogether ceased. In 5 min., slight paralysis; and in 30 min., well marked paralysis, which had not perceptibly lessened in 1 hour 50 min. Frequently tremors occurred, and on several occasions there were feeble general spasms.
b	3 lbs. 10 oz.	0·145 (= 0·12 gr. p. 3 lbs.)	0	0	Death, in 44 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
218. *a* [Experiment *b* was performed twelve days after experiment *a*.]	3 lbs. 4 oz.	0·26	1·3	1·2	Recovery.	*With physostigma*, none. The original size was $\frac{13}{50} \times \frac{13}{50}$. *After atropia*, the size was in 1 min., $\frac{16}{50} \times \frac{16}{50}$; and in 2 hours, $\frac{18}{50} \times \frac{18}{50}$. —On the following day, it was $\frac{16}{50} \times \frac{16}{50}$; and on the 4th day, $\frac{15}{50} \times \frac{15}{50}$.	*With physostigma*, in 4 min., slowing from 39 to 35 per 10 sec. *After atropia*, the rate per 10 sec. was in 1 min. 20 sec., 56; in 15 min., about 62; and in 2 hours, 50.—On the following day, it was 19; and on the 4th day, 36.	*With physostigma*, none noted. The original rate was 27 per 10 sec. *After atropia*, the rate per 10 sec. was in 40 sec., 32; in 11 min., 41; in 35 min., 12; in 1 hour 30 min., 12; and in 2 hours, 17.	*With physostigma*, none. *After atropia*, none. There was no salivation, defæcation, nor urination during the 2 hours of continuous observation.	*With physostigma*, in 1 min. 10 sec., slight fibrillary twitches. *After atropia*, the fibrillary twitches soon became very well marked, but in 2 hours they were only pretty well marked. In 6 min., slight paralysis; in 50 min., very well marked paralysis; and in 2 hours, well marked, though lessened, paralysis. Frequently, weak tremors occurred, and on several occasions there were feeble confused movements.
b	3 lbs. 11 oz.	0·147 (= 0·12 gr. p. 3 lbs.)	0	0	Death, in 27 min.	—	—	—	—	—
219.	4 lbs. 2 oz.	0·33	1·73	1·3	Death, in 50 min. after the administration of physostigma.	*With physostigma*, in 3 min., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{13}{50} \times \frac{12}{50}$. *After atropia*, the size was in 6 min., $\frac{17}{60} \times \frac{17}{60}$; and in 42 min., $\frac{17}{50} \times \frac{17}{50}$. —After death, it was in 1 min., $\frac{15}{60} \times \frac{15}{60}$; in 5 min., $\frac{13}{50} \times \frac{13}{50}$; and in 1 hour 38 min., $\frac{13}{50} \times \frac{13}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 43 to 34 per 10 sec. *After atropia*, the rate per 10 sec. was in 28 min., 60; in 33 min., 50; in 38 min., 32; and in 44 min., 27.	*With physostigma*, in 3 min. 30 sec., acceleration from 23 to 33 per 10 sec. *After atropia*, the rate per 10 sec. was in 3 min., 25; in 15 min., 18; in 28 min., 13; and in 31 min., 8. Afterwards, only infrequent and gasping respiratory movements took place.	*With physostigma*, none. *After atropia*, none. There was no defæcation, urination, nor salivation.	*With physostigma*, in 1 min. 30 sec., infrequent and slight fibrillary twitches. *After atropia*, the fibrillary twitches soon became well marked, but in 28 min. they had altogether ceased. In 11 min., decided paralysis; and in 15 min., general flaccidity. Tremors and weak general spasms frequently occurred.—Rigor began to set in at about 1 hour 30 min. after death (temp. of laboratory, 63° F.).
220.	3 lbs. 6 oz.	0·27	1·46	1·3	Death, in 1 hour 3 min. after the administration of physostigma.	*With physostigma*, in 3 min., dilatation from $\frac{13}{50} \times \frac{12}{50}$ to $\frac{14}{50} \times \frac{13}{50}$. *After atropia*, the size was in 5 min., $\frac{13}{60} \times \frac{13}{60}$; and in 57 min., $\frac{19}{50} \times \frac{19}{50}$. —After death, it was in 1 min., $\frac{14}{60} \times \frac{13}{60}$; in 3 min., $\frac{10}{60} \times \frac{9}{50}$; and in 30 min., $\frac{11}{50} \times \frac{11}{50}$.	*With physostigma*, in 4 min., slowing from 40 to 30 per 10 sec. *After atropia*, the rate per 10 sec. was in 8 min., 54; in 48 min., 48; and in 53 min., 22.	*With physostigma*, in 2 min., acceleration from 26 to 32 per 10 sec. *After atropia*, the rate per 10 sec. was in 4 min., 31; in 13 min., 41; in 20 min., 17; in 35 min., 14; and in 41 min., 11. Soon afterwards, infrequent gasps only took place.	*With physostigma*, in 2 min., slight increase in the secretion of certain buccal glands. *After atropia*, the above increase continued for only a few min. There was no defæcation, urination, nor salivation.	*With physostigma*, in 3 min., pretty well-marked fibrillary twitches. *After atropia*, the fibrillary twitches became well marked, but they had greatly lessened before death. In 11 min., slight paralysis; and in 36 min., general flaccidity. Frequently tremors occurred, and on several occasions feeble general spasms.—There was no rigor 28 min. after death.

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
221.	3 lbs.	0·24	1·5	1·5	Death, in 1 hour 4 min. after the administration of physostigma.	*With physostigma*, none. The original size was $\frac{12}{50} \times \frac{11}{50}$. *After atropia*, the size was in 3 min., $\frac{18}{50} \times \frac{16}{50}$; and in 20 min., $\frac{17}{50} \times \frac{17}{50}$, which size remained until death.	*With physostigma*, in 4 min. 30 sec., slowing from 44 to 37 per 10 sec. *After atropia*, none noted.	*With physostigma*, in 3 min., acceleration from 32 to 35 per 10 sec. *After atropia*, the rate per 10 sec. was in 12 min., 34; and in 26 min., 16.	*With physostigma*, none. *After atropia*, in 1 min., slight increase in the secretion of certain buccal glands, which ceased in a few min. There was no defæcation, urination, nor salivation.	*With physostigma*, in 3 min. 30 sec., pretty well marked fibrillary twitches. *After atropia*, the fibrillary twitches soon became very well marked, and they continued so until a few minutes before death. In 8 min., slight paralysis; in 24 min., well-marked paralysis; and in 44 min., flaccidity. Occasionally tremors occurred.
222.	3 lbs. 10 oz.	0·29	2·4	2	Death, in 1 hour 11 min. after the administration of physostigma.	*With physostigma*, none. The original size was $\frac{13}{50} \times \frac{12}{50}$. *After atropia*, the size was in 2 min., $\frac{17}{50} \times \frac{17}{50}$; and in 1 hour 5 min., $\frac{17}{50} \times \frac{17}{50}$.—After death, it was in 2 min., $\frac{16}{50} \times \frac{16}{50}$; and in 9 min., $\frac{10}{50} \times \frac{9}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 47 to 38 per 10 sec. *After atropia*, the rate per 10 sec. was in 3 min., 51; and in 30 min., 60.	*With physostigma*, none. The original rate was 34 per 10 sec. *After atropia*, the rate per 10 sec. was in 20 min., 45; in 30 min., 22; in 57 min., 9; and in 1 hour, 7. Afterwards, only gasping or feeble non-rhythmical respiratory movements took place.	*With physostigma*, none. *After atropia*, none. There was no defæcation, urination, nor salivation.	*With physostigma*, in 3 min., pretty well-marked fibrillary twitches. *After atropia*, in 40 min., the twitches had become very slight, and they soon disappeared. In 17 min., distinct paralysis; in 45 min., well-marked paralysis; and in 1 hour, general flaccidity. Tremors frequently occurred.
223.	3 lbs.	0·24	2·5	2·5	Death, in 54 min. after the administration of physostigma.	*With physostigma*, none noted. The original size was $\frac{15}{50} \times \frac{14}{50}$. *After atropia*, the size was in 35 min., $\frac{18}{50} \times \frac{18}{50}$, and this size remained until death.—After death, it was in 2 min., $\frac{14}{50} \times \frac{14}{50}$; and in 10 min., $\frac{7}{50} \times \frac{6}{50}$.	*With physostigma*, in 4 min., slowing from 34 to 28 per 10 sec. *After atropia*, the rate per 10 sec. was in 4 min., 53; in 35 min., 55; and in 42 min., 43.	*With physostigma*, none. The original rate was 18 per 10 sec. *After atropia*, the rate per 10 sec. was in 35 min., 22; in 40 min., 7; and in 43 min., 4. Afterwards, gasps and imperfect respiratory movements only occurred.	*With physostigma*, none. *After atropia*, none. There was no defæcation, urination, nor salivation.	*With physostigma*, in 2 min., slight fibrillary twitches. *After atropia*, the twitches became pretty well marked, but they soon altogether disappeared. In 5 min., slight paralysis; in 30 min., well-marked paralysis; and in 45 min., general flaccidity. Tremors frequently occurred. — Rigor began to set in at about 40 min. after death.

TABLE 5.—EXPERIMENTS WITH TWO AND A HALF TIMES THE MINIMUM-LETHAL DOSE OF PHYSOSTIGMA (0·3 *gr. of Sulphate of Physostigmia per Three Pounds Weight of Rabbit*).

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
224.	3 lbs.	0·3	0·05	0·05	Death, in 30 min. after the administration of physostigma.	*With physostigma*, none. The original size was $\frac{13}{50} \times \frac{12}{50}$. *After atropia*, the size was in 4 min., $\frac{18}{50} \times \frac{18}{50}$; in 8 min., $\frac{10}{50} \times \frac{9}{50}$; in 9 min., $\frac{8}{50} \times \frac{7}{50}$; in 13 min., $\frac{7}{50} \times \frac{6}{50}$; and in 24 min., $\frac{10}{50} \times \frac{10}{50}$.—After death, it was in 1 min., $\frac{9}{50} \times \frac{8}{50}$; and in 20 min., $\frac{10}{50} \times \frac{9}{50}$.	*With physostigma*, in 4 min., 30 sec., slowing from 40 to 32 per 10 sec. *After atropia*, the rate per 10 sec. was in 4 min., 57; in 11 min., 32; and in 21 min., 19.	*With physostigma*, in 2 min., slowing from 20 to 18 per 10 sec. *After atropia*, the rate per 10 sec. was in 13 min., 10; and in 20 min., 6. Afterwards only infrequent gasps occurred.	*With physostigma*, none. *After atropia*, in 4 min., several fæcal pellets were passed; in 13 min., urine was voided; and in 23 min., salivation began.	*With physostigma*, in 1 min. 30 sec., slight fibrillary twitches. *After atropia*, the fibrillary twitches soon became well marked, and continued so until death. In 3 min., slight paralysis; and in 10 min., general flaccidity. Frequently tremors took place.—Rigor began to set in at 58 min. after death (temp. of laboratory, 62° F.)
225.	3 lbs.	0·3	0·08	0·08	Death, in 1 hour after the administration of physostigma.	*With physostigma*, none. The original size was $\frac{14}{50} \times \frac{13}{50}$. *After atropia*, the size was in 4 min., $\frac{17}{50} \times \frac{17}{50}$; in 9 min., $\frac{19}{50} \times \frac{19}{50}$; and in 55 min., $\frac{19}{50} \times \frac{19}{50}$. —After death, it was in 4 min., $\frac{17}{50} \times \frac{17}{50}$; and in 10 min., $\frac{14}{50} \times \frac{14}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 40 to 31 per 10 sec. *After atropia*, the rate per 10 sec. was in 8 min., 50; in 33 min., 28; and in 43 min., 26.	*With physostigma*, none. The original rate was 18 per 10 sec. *After atropia*, the rate per 10 sec. was in 13 min., 21; in 22 min., 13; and in 31 min., 5. Soon afterwards the respirations became gasping and very irregular in their occurrence.	*With physostigma*, none. *After atropia*, in 30 sec., slight increase in the secretion of certain buccal glands, which caused noisy respiration in 22 min., but had altogether ceased in 26 min. There was no defæcation, urination, nor salivation.	*With physostigma*, in 2 min., slight fibrillary twitches. *After atropia*, the fibrillary twitches soon became well marked, but they were only slight after 24 min. In 8 min., distinct paralysis; and in 28 min., general flaccidity. Tremors and feeble spasmodic movements occurred.
226. *a* [Experiment *b* was performed nine days after experiment *a*.]	3 lbs. 12 oz.	0·37	0·12	0·1	Recovery.	*With physostigma*, in 4 min., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{13}{50} \times \frac{12}{50}$. *After atropia*, the size was in 8 min., $\frac{19}{50} \times \frac{19}{50}$; and in 2 hours 28 min., $\frac{19}{50} \times \frac{19}{50}$.—On the following day, it was $\frac{15}{50} \times \frac{14}{50}$; and on the 7th day, $\frac{13}{50} \times \frac{12}{50}$.	*With physostigma*, in 3 min. 30 sec., slowing from 40 to 32 per 10 sec. *After atropia*, the rate per 10 sec. was in 3 min., 60; and in 2 hours 30 min., 47.—On the following day, it was 31; and on the 3d day, 41.	*With physostigma*, none noted. The original rate was 23 per 10 sec. *After atropia*, the rate per 10 sec was in 1 hour 30 min., 13; and in 2 hours 30 min., 15.—On the following day, it was 17.	*With physostigma*, none. *After atropia*, none. There was no defæcation, urination, nor salivation, during the 2 hours 43 min. of continuous observation.	*With physostigma*, in 3 min., slight fibrillary twitches; and in 4 min. 30 sec., slight paralysis. *After atropia*, the fibrillary twitches soon became very well marked; but they had considerably lessened by 2 hours 40 min. In 20 min., well-marked paralysis, which increased somewhat, and then at about 2 hours 30 min., began to lessen. Frequently weak tremors occurred.
b	3 lbs. 12 oz.	0·15 (= 0·12 gr. p. 3 lbs.)	0	0	Death in 38 min.	—	—	—	—	—

Number of Experiment.		Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
227.	*a*	3 lbs. [Experiment *b* was performed eight days after experiment *a*.]	0·3	0·15	0·15	Recovery.	*With physostigma*, in 3 min. 30 sec., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{14}{50} \times \frac{13}{50}$. *After atropia*, the size was in 8 min., $\frac{16}{50} \times \frac{16}{50}$; in 12 min., $\frac{17}{50} \times \frac{17}{50}$; and in 1 hour 5 min., $\frac{16}{50} \times \frac{16}{50}$.—On the following day, it was $\frac{15}{50} \times \frac{14}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 41 to 33 per 10 sec. *After atropia*, the rate per 10 sec. was in 8 min., 54; and in 1 hour 21 min., 48.—On the following day, it was 33; and on the 4th day, 34.	*With physostigma*, none noted. The original rate was 21 per 10 sec. *After atropia*, the rate per 10 sec. was in 20 min., 18; and in 1 hour, 19.—On the following day, it was 13; and on the 4th day, 16.	*With physostigma*, none. *After atropia*, in 2 min., slight increase in the secretion of certain buccal glands. There was no defæcation, urination, nor salivation.	*With physostigma*, in 2 min., slight fibrillary twitches. *After atropia*, the fibrillary twitches soon became very well marked, and they continued so for at least 1 hour 21 min. In 1 min., extension of limbs; in 4 min., slight paralysis; and in 18 min., well-marked paralysis, which had not obviously lessened, in 1 hour 21 min. Occasionally feeble tremors occurred.
	b	3 lbs.	0·12	0	0	Death, in 26 min.	—	—	—	—	—
228.	*a*	3 lbs. 4 oz. [Experiment *b* was performed ten days after experiment *a*.]	0·325	0·214	0·2	Recovery.	*With physostigma*, none noted. The original size was $\frac{14}{50} \times \frac{13}{50}$. *After atropia*, the size was in 2 min., $\frac{18}{50} \times \frac{18}{50}$; in 20 min., $\frac{19}{50} \times \frac{19}{50}$; and in 1 hour 30 min., $\frac{18}{50} \times \frac{18}{50}$.—On the 3d day, it was $\frac{14}{50} \times \frac{13}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 42 to 38 per 10 sec. *After atropia*, the rate per 10 sec. was in 1 hour 10 min., about 52; and in 1 hour 40 min., 48.—On the 3d day, it was 42.	*With physostigma*, none. The original rate was 42 per 10 sec. *After atropia*, the rate per 10 sec. was in 20 min., 29; in 1 hour 10 min., 19; and in 1 hour 33 min., 19.—On the 3d day, it was 20.	*With physostigma*, none. *After atropia*, in 2 min., slight increase in the secretion of certain buccal glands. There was no defæcation, urination, nor salivation during the 1 hour and 40 min. of continuous observation.	*With physostigma*, in 2 min., slight fibrillary twitches. *After atropia*, the fibrillary twitches soon became very well marked, and continued so for at least 1 hour and 40 min. In 13 min., distinct paralysis; and in 33 min., well-marked paralysis, which had somewhat lessened at 1 hour 40 min. Rarely, feeble tremors occurred.
	b	3 lbs. 4 oz.	0·13 (= 0·12 gr. per 3 lbs.)	0	0	Death, in 18 min.	—	—	—	—	—
229.	*a*	3 lbs. [Experiment *b* was performed ten days after experiment *a*.]	0·3	0·3	0·3	Recovery.	*With physostigma*, none noted. The original size was $\frac{12}{50} \times \frac{11}{50}$. *After atropia*, the size was in 3 min., $\frac{17}{50} \times \frac{17}{50}$; in 10 min., $\frac{19}{50} \times \frac{19}{50}$; and in 1 hour, $\frac{18}{50} \times \frac{18}{50}$.—On the following day, it was $\frac{17}{50} \times \frac{17}{50}$; on the 4th day, $\frac{13}{50} \times \frac{12}{50}$; and on the 7th day, $\frac{10}{50} \times \frac{9}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 35 to 27 per 10 sec. *After atropia*, the rate per 10 sec. was in 6 min., 61; and in 48 min., 64.—On the following day, it was 25; and on the 3d day, 41.	*With physostigma*, none noted. The original rate was 18 per 10 sec. *After atropia*, the rate per 10 sec. was in 40 min., 23; and in 48 min., 18.—On the following day, it was 21; and on the 3d day, 18.	*With physostigma*, none. *After atropia*, in 1 min., slight increase in the secretion of certain buccal glands, which soon ceased. Rarely, moist laryngeal sounds accompanied the respirations. In 40 min., normal fæcal pellets were passed. There was no urination nor salivation during the 1 hour and 15 min. of continuous observation.	*With physostigma*, in 3 min., slight fibrillary twitches. *After atropia*, the fibrillary twitches became well marked, and continued so for at least 1 hour. In 15 min., slight paralysis; and in 20 min., well-marked paralysis, which had not obviously diminished at 1 hour 15 min. Occasionally, tremors occurred.
	b	3 lbs. 4 oz.	0·13 (= 0·12 gr. p. 3 lbs.)	0	0	Death, in more than 1 hour 14 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
230. *a* [Experiment *b* was performed nine days after experiment *a*.]	3 lbs. 6 oz.	0·33	0·56	0·5	Recovery.	*With physostigma*, none. The original size was $\frac{10}{50} \times \frac{9}{50}$. *After atropia*, the size was in 8 min., $\frac{16}{50} \times \frac{16}{50}$; and in 2 hours, $\frac{17}{50} \times \frac{17}{50}$.—On the following day, it was $\frac{15}{50} \times \frac{14}{50}$; and on the 4th day, $\frac{8}{50} \times \frac{7}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 38 to 29 per 10 sec. *After atropia*, the rate per 10 sec. was in 3 min., 56; in 50 min., 52; and in 1 hour 3 min., 51.—On the following day, it was 33; on the 3d day, 36; and on the 4th day, 40.	*With physostigma*, in 4 min., acceleration from 21 to 28 per 10 sec. *After atropia*, the rate per 10 sec. was in 4 min., 25; in 53 min., 14; and in 1 hour 3 min., 15.—On the following day, it was 14; and on the 3d day, 30.	*With physostigma*, none. *After atropia*, in 1 hour, a little urine was voided. There was no defæcation, salivation, nor increase in the secretion of any buccal gland during the 1 hour and 4 min. of continuous observation.	*With physostigma*, in 2 min., slight fibrillary twitches. *After atropia*, the fibrillary twitches soon became well marked, but they had lessened somewhat in 1 hour. In 12 min., distinct paralysis; in 50 min., very well marked paralysis; and in 1 hour, well-marked paralysis. Frequently tremors occurred.
	b 3 lbs. 4 oz.	0·13 (= 0·12 gr. p. 3 lbs.)	0	0	Death, in 20 min.	—	—	—	—	—
231. *a* [Experiment *b* was performed twelve days after experiment *a*.]	3 lbs.	0·3	0·6	0·6	Recovery.	*With physostigma*, none noted. The original size was $\frac{13}{50} \times \frac{12}{50}$. *After atropia*, the size was in 4 min., $\frac{15}{50} \times \frac{15}{50}$; in 20 min., $\frac{16}{50} \times \frac{16}{50}$; and in 1 hour 21 min., $\frac{15}{50} \times \frac{15}{50}$.—On the following day, it was $\frac{15}{50} \times \frac{15}{50}$; and on the 3d day, $\frac{14}{50} \times \frac{14}{50}$.	*With phyostigma*, in 4 min. 30 sec., slowing from 39 to 32 per 10 sec. *After atropia*, the rate per 10 sec. was in 10 min., 58; in 1 hour 5 min., about 52; and in 1 hour 22 min., 43.—On the following day, it was 41.	*With physostigma*, in 3 min. 30 sec., slowing from 27 to 23 per 10 sec. *After atropia*, the rate per 10 sec. was in 26 min., 21; in 1 hour 4 min., 18; and in 1 hour 21 min., 24.—On the following day, it was 18.	*With physostigma*, none. *After atropia*, in 1 hour 18 min., several normal fæcal pellets were passed, and urine was voided. There was no salivation during the 1 hour and 24 min. of continuous observation.	*With physostigma*, in 2 min., slight fibrillary twitches. *After atropia*, the fibrillary twitches soon became well marked, and continued so for at least 1 hour 15 min. In 9 min., distinct paralysis; in 50 min., well-marked paralysis; and in 1 hour 24 min., distinct, though pretty lessened, paralysis. Frequently, tremors occurred.
	b 3 lbs. 2 oz.	0·125 (= 0·12 gr. p. 3 lbs.)	0	0	Death, in 22 min.	—	—	—	—	—
232. *a* [Experiment *b* was performed ten days after experiment *a*.]	3 lbs. 8 oz.	0·35	0·81	0·7	Recovery.	*With physostigma*, none. The original size was $\frac{13}{50} \times \frac{12}{50}$. *After atropia*, the size was in 4 min., $\frac{16}{50} \times \frac{16}{50}$; in 20 min., $\frac{17}{50} \times \frac{17}{50}$; and in 2 hours 40 min., $\frac{18}{50} \times \frac{18}{50}$.—On the following day, it was $\frac{18}{50} \times \frac{18}{50}$; and on the 5th day, $\frac{18}{50} \times \frac{18}{50}$.	*With physostigma*, in 4 min., slowing from 37 to 31 per 10 sec. *After atropia*, the rate per 10 sec. was in 5 min., 60; and in 2 hours 14 min., 56.—On the following day, it was 26; on the 4th day, 32; and on the 5th day, 37.	*With physostigma*, none noted. The original rate was 12 per 10 sec. *After atropia*, the rate per 10 sec. was in 40 min., 14; in 1 hour, 11; in 1 hour 16 min., 9; in 1 hour 20 min., 12; and in 2 hours 15 min., 11.—On the following day, it was 12.	*With physostigma*, none. *After atropia*, in 2 hours, several normal fæcal pellets were passed. There was no urination nor salivation during the 2 hours and 40 min. of continuous observation.	*With physostigma*, in 1 min. 30 sec., slight fibrillary twitches. *After atropia*, the fibrillary twitches soon became very well marked, but they had lessened considerably in 2 hours. In 12 min., slight paralysis; in 1 hour 20 min., very well-marked paralysis; and in 2 hours 40 min., well-marked paralysis. Frequently, tremors and weak starts occurred.
	b 3 lbs. 8 oz.	0·14 (= 0·12 gr. p. 3 lbs.)	0	0	Death, in 21 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Dose p. 3 lbs. of Animal.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
233. *a*	3 lbs. 7 oz.	0·34 [Experiment *b* was performed twelve days after experiment *a*.]	0·91	0·8	Recovery.	*With physostigma*, none. The original size was $\frac{13}{50} \times \frac{12}{50}$. *After atropia*, the size was in 2 min., $\frac{15}{50} \times \frac{15}{50}$; in 9 min., $\frac{17}{50} \times \frac{17}{50}$; in 30 min., $\frac{15}{50} \times \frac{14}{50}$; in 1 hour 20 min., $\frac{13}{50} \times \frac{12}{50}$; and in 2 hours 35 min., $\frac{9}{50} \times \frac{8}{50}$.—On the following day, it was $\frac{16}{50} \times \frac{15}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 37 to 29 per 10 sec. *After atropia*, the rate per 10 sec. was in 7 min., 54; in 1 hour 26 min., 34; and in 1 hour 50 min., 29.—On the following day, it was 25; on the 3d day, 33; and on the 4th day, 39.	*With physostigma*, none. The original rate was 10 per 10 sec. *After atropia*, the rate per 10 sec. was in 15 min., 20; in 41 min., 14; in 1 hour 20 min., 13; in 1 hour 26 min., 10; in 1 hour 50 min., 15; and in 2 hours 46 min., 19.—On the following day, it was 13.	*With physostigma*, none. *After atropia*, in 1 min., slight increase in the secretion of certain buccal glands, which ceased in a few minutes. In 29 min., in 1 hour 19 min., in 1 hour 54 min., and in 2 hours 19 min., several normal fæcal pellets were passed. In 1 hour 40 min., and in 2 hours 52 min., urine was voided. In 1 hour 50 min., salivation commenced, and continued at least 2 hours 55 min. In 2 hours 15 min., the respirations became noisy.	*With physostigma*, in 1 min. 20 sec., slight fibrillary twitches. *After atropia*, the fibrillary twitches soon became pretty well marked, and continued so until at least 2 hours 55 min. In 10 min., slight paralysis; in 1 hour 6 min., well-marked paralysis; and in 2 hours, almost no paralysis. Frequently weak tremors occurred; and at 2 hours 10 min., and 2 hours 34 min., feeble general convulsions took place.
b	3 lbs. 4 oz.	0·13 (= 0·12 gr. p. 3 lbs.)	0	0	Death, in 18 min.	—	—	—	—	—
234.	2 lbs. 12 oz.	0·275	0·75	0·8	Death, in more than 3 hours 22 min. and less than 24 hours after the administration of physostigma.	*With physostigma*, none. The original size was $\frac{15}{50} \times \frac{14}{50}$. *After atropia*, the size was in 5 min., $\frac{17}{50} \times \frac{17}{50}$; in 13 min., $\frac{19}{50} \times \frac{19}{50}$; and in 1 hour 53 min., $\frac{17}{50} \times \frac{17}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 39 to 31 per 10 sec. *After atropia*, the rate per 10 sec. was in 43 min., 57; in 1 hour 8 min., 40; and in 1 hour 32 min., 44.	*With physostigma*, in 4 min., acceleration from 19 to 22 per 10 sec. *After atropia*, the rate per 10 sec. was in 12 min., 21; in 42 min., 20; in 1 hour 8 min., 13; and in 1 hour 32 min., 17.	*With physostigma*, none. *After atropia*, in 2 min., slight increase in the secretion of certain buccal glands, which ceased in a few minutes. In 1 hour 53 min., salivation occurred, and the respirations were occasionally noisy. There was no defæcation nor urination during the 3 hours 17 min. of continuous observation.	*With physostigma*, in 1 min. 30 sec., slight fibrillary twitches. *After atropia*, the fibrillary twitches soon became pretty well marked, and continued so for at least 2 hours. In 7 min., slight paralysis; and in 50 min., well-marked paralysis, which had not obviously lessened in 3 hours 10 min. Tremors and starts frequently occurred, and they could be excited by touching the animal.
235.	3 lbs. 5 oz.	0·33	0·99	0·9	Death, in 1 hour 3 min. after the administration of physostigma.	*With physostigma*, none. The original size was $\frac{14}{50} \times \frac{13}{50}$. *After atropia*, the size was in 10 min., $\frac{18}{50} \times \frac{18}{50}$; and in 58 min., $\frac{18}{50} \times \frac{18}{50}$. —After death, it was in 1 min., $\frac{12}{50} \times \frac{12}{50}$; in 5 min., $\frac{6}{50} \times \frac{5}{50}$; and in 46 min., $\frac{8}{50} \times \frac{7}{50}$.	*With physostigma*, in 4 min., slowing from 42 to 37 per 10 sec. *After atropia*, the rate per 10 sec. was in 8 min., 60; in 52 min., 46; in 54 min., 41; and in 56 min., 36.	*With physostigma*, none. The original rate was 32 per 10 sec. *After atropia*, the rate per 10 sec. was in 22 min., 32; in 42 min., 19; and in 51 min., 5. Afterwards, only infrequent gasping movements occurred, often non-rhythmical or imperfect.	*With physostigma*, none. *After atropia*, in 48 min., urine was voided. There was neither defæcation nor salivation.	*With physostigma*, in 1 min. 30 sec., slight fibrillary twitches. *After atropia*, the twitches soon become very well marked, but shortly before death they had lessened considerably. In 11 min., distinct paralysis; and in 50 min., general flaccidity. Occasionally feeble tremors occurred.—Rigor began to set in at about 45 min. after death (temp. of laboratory, 63° F.).

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
236.	2 lbs. 14 oz.	0·287	0·95	1	Death, in 52 min. after the administration of physostigma.	*With physostigma*, none. The original size was $\frac{14}{50} \times \frac{13}{50}$. *After atropia*, the size was in 2 min. 30 sec., $\frac{13}{50} \times \frac{13}{50}$; in 18 min., $\frac{19}{50} \times \frac{19}{50}$; and in 47 min., $\frac{19}{50} \times \frac{19}{50}$.—After death, it was in 1 min., $\frac{17}{50} \times \frac{17}{50}$; and in 2 min., $\frac{15}{50} \times \frac{15}{50}$; in 8 min., $\frac{14}{50} \times \frac{14}{50}$; and in 24 min., $\frac{14}{50} \times \frac{14}{50}$.	*With physostigma*, in 4 min., slowing from 42 to 29 per 10 sec. *After atropia*, the rate per 10 sec. was in 4 min., 53; and in 45 min., 36.	*With physostigma*, none. The original rate was 13 per 10 sec. *After atropia*, the rate per 10 sec. was in 16 min., 15; in 23 min., 13; and in 40 min., 6. Afterwards only rare and laboured gasps occurred.	*With physostigma*, in 4 min., slight increase in the secretion of certain buccal glands. *After atropia*, in 30 sec., slight increase in the secretion of certain buccal glands, which ceased in a few minutes. There was no defæcation, urination, nor salivation.	*With physostigma*, in 1 min. 30 sec., slight fibrillary twitches. *After atropia*, the twitches soon became pretty well marked, but they altogether ceased before death. In 8 min., slight paralysis; and in 40 min., general flaccidity. Frequently tremors and starts occurred.
237.	3 lbs.	0·3	1·5	1·5	Death, in 58 min. after the administration of physostigma.	*With physostigma*, in 3 min., dilatation from $\frac{11}{50} \times \frac{10}{50}$ to $\frac{13}{50} \times \frac{12}{50}$. *After atropia*, the size was in 2 min., $\frac{15}{50} \times \frac{15}{50}$; and in 52 min., $\frac{17}{50} \times \frac{17}{50}$.—After death, it was in 2 min., $\frac{15}{50} \times \frac{15}{50}$; and in 10 min., $\frac{10}{50} \times \frac{9}{50}$.	*With physostigma*, in 4 min., slowing from 40 to 32 per 10 sec. *After atropia*, the rate per 10 sec. was in 3 min., 48.	*With physostigma*, none. The original rate was 12 per 10 sec. *After atropia*, the rate per 10 sec. was in 3 min., 13; in 34 min., 19; and in 41 min., 6. Afterwards, only infrequent gasps took place.	*With physostigma*, none. *After atropia*, in 1 min., slight increase in the secretion of certain buccal glands, which ceased in a few minutes. There was no defæcation, urination, nor salivation.	*With physostigma*, in 2 min., slight fibrillary twitches. *After atropia*, the fibrillary twitches remained only slightly marked. In 3 min., slight paralysis; and in 35 min., general flaccidity. Rarely, some feeble tremors occurred.

SERIES II.—*continued.*

TABLE 6.—EXPERIMENTS WITH THREE TIMES THE MINIMUM-LETHAL DOSE OF PHYSOSTIGMA (0·36 *gr. of Sulphate of Physostigmia per Three Pounds Weight of Rabbit*).

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
238.	3 lbs. 6 oz.	0·405	0·11	0·1	Death, in 1 hour 2 min. after the administration of physostigma.	*With physostigma*, none. The original size was $\frac{15}{50} \times \frac{14}{50}$. *After atropia*, the size was in 2 min., $\frac{17}{50} \times \frac{17}{50}$; in 28 min., $\frac{15}{50} \times \frac{14}{50}$; in 35 min., $\frac{12}{50} \times \frac{11}{50}$; and in 44 min., $\frac{12}{50} \times \frac{11}{50}$.	*With physostigma*, in 4 min., slowing from 43 to 36 per 10 sec. *After atropia*, the rate per 10 sec. was in 2 min. 30 sec., 44; in 29 min., 37; and in 52 min., 17.	*With physostigma*, none. The original rate was 34 per 10 sec. *After atropia*, the rate per 10 sec. was in 27 min., 10; in 34 min., 14; and in 40 min., 7. Afterwards only feeble and irregular gasps occurred.	*With physostigma*, none. *After atropia*, in 1 min., slight increase in the secretion of certain buccal glands, which ceased in a few minutes. There was no defæcation, urination, nor salivation.	*With physostigma*, in 1 min. 30 sec., slight fibrillary twitches. *After atropia*, the twitches soon became well marked, but in 35 min. they had greatly lessened. In 20 min., very well-marked paralysis; and in 30 min., general flaccidity. Frequently tremors and irregular movements, suggestive of dyspnœa, occurred.—After death, the first appearance of rigor was in 1 hour 30 min. (temp. of labo-

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
239.	3 lbs.	0·36	0·15	0·15	Death, in 33 min. after the administration of physostigma.	*With physostigma*, none noted. The original size was $\frac{12}{50} \times \frac{11}{50}$. *After atropia*, the size was in 2 min. 30 sec., $\frac{15}{50} \times \frac{15}{50}$; in 9 min., $\frac{17}{50} \times \frac{17}{50}$; in 18 min., $\frac{9}{50} \times \frac{8}{50}$; and in 28 min., $\frac{9}{50} \times \frac{8}{50}$.—After death, it was in 1 min. 30 sec., $\frac{6}{50} \times \frac{5}{50}$; in 2 min., $\frac{5}{50} \times \frac{4}{50}$; in 15 min., $\frac{7}{50} \times \frac{6}{50}$; and in 20 min., $\frac{10}{50} \times \frac{9}{50}$.	*With physostigma*, in 4 min., slowing from 42 to 38 per 10 sec. *After atropia*, the rate per 10 sec. was in 4 min., 50. Further observations were not made, as the attempts to make them interfered greatly with the respiratory movements.	*With physostigma*, none. The original rate was 17 per 10 sec. *After atropia*, the respirations soon became very laboured and infrequent.	*With physostigma*, none. *After atropia*, in 2 min., slight increase in the secretion of certain buccal glands, which ceased in a few minutes. In 25 min., several normal fæcal pellets were formed. There was no urination nor salivation.	*With physostigma*, in 1 min. 30 sec., slight fibrillary twitches; and in 4 min. 30 sec., pretty well marked and more general twitches. *After atropia*, the fibrillary twitches soon became very well marked, and they continued, though in a diminished form, until about 15 min. after death. In 4 min., extension of the limbs; in 8 min., distinct paralysis; and in 14 min., general flaccidity. Frequently tremors and feeble spasms occurred.—After death, the first appearance of rigor was in 25 min. (temp. of laboratory, 59° F.).
240. [Experiment *b* was performed thirteen days after experiment *a*.]										
a	3 lbs. 2 oz.	0·37	0·17	0·16	Recovery.	*With physostigma*, none noted. The original size was $\frac{13}{50} \times \frac{12}{50}$. *After atropia*, the size was in 15 min., $\frac{15}{50} \times \frac{15}{50}$; and in 1 hour 35 min., $\frac{16}{50} \times \frac{15}{50}$.—On the following day, it was $\frac{16}{50} \times \frac{16}{50}$; and on the 4th day, $\frac{16}{50} \times \frac{15}{50}$.	*With physostigma*, none noted. The original rate was 38 per 10 sec. *After atropia*, none noted, until the following day when the rate per 10 sec. was 32. On the 3d day it was 39.	*With physostigma*, none noted. The original rate was 19 per 10 sec. *After atropia*, the rate per 10 sec. was in 24 min., 16; in 50 min., 15; and in 1 hour 30 min., 14.	*With physostigma*, none. *After atropia*, in 7 min., increase in the secretion of certain buccal glands, causing noisy respiration. In 17 min., no sounds with respiration; in 38 min., moist sounds with respiration; and in 50 min., no sounds. There was no defæcation, urination, nor salivation during the 2 hours and 20 min. of continuous observation.	*With physostigma*, in 2 min., slight fibrillary twitches, which had become more marked in 4 min. *After atropia*, the fibrillary twitches soon became well marked, and continued so for more than 2 hours. In 2 min., extension of the limbs; in 5 min., slight paralysis; in 50 min., very well-marked paralysis; and in 2 hours 15 min., well-marked, though somewhat diminished, paralysis. Frequently tremors and feeble spasms occurred.
b	3 lbs. 4 oz.	0·13 (= 0·12 gr. p. 3 lbs.)	0	0	Death, in 16 min.	—	—	—	—	—
241.	3 lbs. 3 oz.	0·37	0·23	0·2	Death, in 53 min. after the administration of physostigma.	*With physostigma*, in 3 min 30 sec., dilatation from $\frac{14}{50} \times \frac{14}{50}$ to $\frac{15}{50} \times \frac{15}{50}$. *After atropia*, the size was in 2 min., $\frac{17}{50} \times \frac{17}{50}$; in 25 min., $\frac{18}{50} \times \frac{18}{50}$; and in 48 min., $\frac{19}{50} \times \frac{19}{50}$.—After death, it was in 1 min., $\frac{19}{50} \times \frac{19}{50}$; in 5 min., $\frac{15}{50} \times \frac{15}{50}$; and in 22 min., $\frac{15}{50} \times \frac{14}{50}$.	*With physostigma*, in 3 min. 50 sec., slowing from 42 to 32 per 10 sec. *After atropia*, the rate per 10 sec. was in 1 min. 30 sec., 49; in 4 min., 52; in 8 min., 57; in 40 min., 48; in 43 min., 37; and in 46 min., 36.	*With physostigma* none. The original rate was 24 per 10 sec. *After atropia*, the rate per 10 sec. was in 7 min., 23; in 33 min., 18; in 37 min., 10; in 42 min., 6; and in 44 min., 4. Afterwards, only feeble gasps occurred irregularly until death.	*With physostigma*, none. *After atropia*, in 3 min., slight increase in the secretion of certain buccal glands; and in 25 min., so great increase as to produce noisy respiration, which occurred at intervals until death. There was no defæcation, urination, nor salivation.	*With physostigma*, in 1 min., 30 sec., slight and infrequent fibrillary twitches; and in 4 min., uneasy movements. *After atropia*, the fibrillary twitches soon became very well marked; they afterwards became less marked, but continued until a few minutes after death. In 6 min., slight extension of the limbs; in 8 min., slight paralysis; and in 36 min., general flaccidity. Frequently, tremors occurred.—After death, there was no rigor in 30 min. (temp. of laboratory, 59° F.).

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility &c.
242.	3 lbs. 4 oz.	0·39	0·27	0·25	Death, in 22 min. after the administration of physostigma.	*With physostigma*, in 3 min. 30 sec., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{15}{50} \times \frac{15}{50}$. *After atropia*, the size was in 3 min., $\frac{17}{50} \times \frac{17}{50}$; and in 17 min., $\frac{17}{50} \times \frac{17}{50}$; —After death, it was in 2 min., $\frac{12}{50} \times \frac{12}{50}$; in 8 min., $\frac{9}{50} \times \frac{8}{50}$; in 19 min., $\frac{11}{50} \times \frac{11}{50}$; and in 1 hour 22 min., $\frac{14}{50} \times \frac{13}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 40 to 29 per 10 sec. *After atropia*, the rate per 10 sec. was in 15 min., 46.	*With physostigma*, in 4 min., acceleration from 28 to 42 per 10 sec. *After atropia*, the rate per 10 sec. was in 4 min., 36; in 11 min., 20; in 13 min., 14; in 15 min., 11; and in 16 min., 10.	*With physostigma*, in 4 min. 30 sec., slight increase in the secretion of certain buccal glands. *After atropia*, none. There was no defæcation, urination, nor salivation.	*With physostigma*, in 2 min., slight and infrequent fibrillary twitches. *After atropia*, the fibrillary twitches soon became very well marked; they afterwards diminished, but continued until about 7 min. after death. In 1 min., extension of the limbs; in 5 min., distinct paralysis; and in 15 min., general flaccidity. Frequently, tremors and feeble spasms occurred.—After death, rigor first began to set in at 50 min. (temp. of laboratory, 63° F.).
243.	3 lbs.	0·36	0·3	0·3	Death, in 1 hour 22 min. after the administration of physostigma.	*With physostigma*, none. The original size was $\frac{12}{50} \times \frac{12}{50}$. *After atropia*, the size was in 2 min., $\frac{15}{50} \times \frac{15}{50}$; in 30 min., $\frac{10}{50} \times \frac{9}{50}$; in 35 min., $\frac{9}{50} \times \frac{8}{50}$; in 1 hour, $\frac{8}{50} \times \frac{7}{50}$; and in 1 hour 13 min., $\frac{6}{50} \times \frac{5}{50}$. —After death, it was in 1 min., $\frac{6}{50} \times \frac{5}{50}$; in 32 min., $\frac{6}{50} \times \frac{5}{50}$; in 42 min., $\frac{7}{50} \times \frac{6}{50}$; in 58 min., $\frac{8}{50} \times \frac{7}{50}$; and in 1 hour 10 min., $\frac{10}{50} \times \frac{10}{50}$.	*With physostigma*, none noted. The original rate was 42 per 10 sec. *After atropia*, the rate per 10 sec. was in 6 min., 56; in 36 min., 57; and in 1 hour 4 min., 35.	*With physostigma*, none noted. The original rate was 32 per 10 sec. *After atropia*, the rate per 10 sec. was in 10 min., 20; in 36 min., 10; in 50 min., 6; and in 1 hour 4 min., 5. Afterwards feeble gasps occurred irregularly until death.	*With physostigma*, none noted. *After atropia*, in 1 hour 10 min., slight salivation; and after this, twice the feeble respiratory gasps were accompanied with moist sounds. There was no defæcation nor urination.	*With physostigma* in 1 min. 30 sec., slight and infrequent fibrillary twitches. *After atropia*, the fibrillary twitches soon became well marked, and they were present, though in only a slight form, until 8 min. after death. In 2 min., extension of the limbs; in 4 min., slight paralysis; and in 35 min., general flaccidity. Frequently, tremors and feeble spasms occurred.—Rigor first began to set in at about 1 hour after death (temp. of laboratory, 61° F.).
244.	3 lbs. 2 oz.	0·37	0·52	0·5	Death, in more than 1 hour 10 min. after the administration of physostigma.	*With physostigma*, none noted. The original size was $\frac{14}{50} \times \frac{13}{50}$. *After atropia*, the size was in 12 min., $\frac{18}{50} \times \frac{18}{50}$; and in 1 hour 5 min., $\frac{18}{50} \times \frac{18}{50}$.—After death, on the following day the size was $\frac{17}{50} \times \frac{16}{50}$.	*With physostigma*, in 4 min., slowing from 40 to 32 per 10 sec. *After atropia*, the rate per 10 sec. was in 3 min., 48; in 10 min., 57; and in 35 min., 55.	*With physostigma*, none. The original rate was 16 per 10 sec. *After atropia*, the rate per 10 sec. was in 8 min., 21; and in 52 min., 12.	*With physostigma*, none. *After atropia*, in 2 min., slight increase in the secretion of certain buccal glands, which ceased in a few minutes. There was no defæcation, urination, nor salivation.	*With physostigma*, in 2 min., slight and infrequent fibrillary twitches; and in 4 min. 30 sec., uneasy movements. *After atropia*, the fibrillary twitches soon became well marked, and they were frequent, though in a diminished form, at 1 hour. In 2 min., extension of the limbs; and in 1 hour, general flaccidity. Frequently, tremors and pretty strong spasms occurred.

EXPERIMENTS WITH THREE AND A HALF TIMES THE MINIMUM-LETHAL DOSE OF PHYSOSTIGMA (0·42 *gr. of Sulphate of Physostigmia per Three Pounds Weight of Rabbit*).

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
245.	3 lbs. 5 oz.	0·46	0·17	0·16	Death, in 22 min. after the administration of physostigma.	*With physostigma*, in 4 min., dilatation from $\frac{15}{50} \times \frac{14}{50}$ to $\frac{18}{50} \times \frac{16}{50}$. *After atropia*, the size was in 8 min., $\frac{9}{50} \times \frac{8}{50}$; in 10 min., $\frac{7}{50} \times \frac{6}{50}$; in 15 min., $\frac{10}{50} \times \frac{10}{50}$; and in 16 min. 30 sec., $\frac{9}{50} \times \frac{8}{50}$.—After death, it was in 30 sec., $\frac{6}{50} \times \frac{5}{50}$; in 1 min., $\frac{5}{50} \times \frac{4}{50}$; in 8 min., $\frac{6}{50} \times \frac{5}{50}$; in 23 min., $\frac{9}{50} \times \frac{8}{50}$; and in 36 min., $\frac{10}{50} \times \frac{10}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 32 to 27 per 10 sec. *After atropia*, the rate per 10 sec. was in 8 min., 36; and in 15 min. 30 sec., 19.	*With physostigma*, in 3 min. 50 sec., acceleration from 14 to 18 per 10 sec. *After atropia*, in 3 min., the respirations became noisy; in 8 min., they were gasping, infrequent, impeded by mucus, and irregular; and they continued so until death.	*With physostigma*, none. *After atropia*, in 1 min., the secretion of certain buccal glands was increased; and in 14 min. salivation occurred. In 11 min., normal fæcal pellets were passed. There was no urination.	*With physostigma*, in 2 min., slight and infrequent fibrillary twitches; and in 4 min., uneasy movements. *After atropia*, the fibrillary twitches soon became pretty well marked, and they continued for some minutes after death. In 1 min., extension of the limbs; and in 6 min., general flaccidity. Occasionally, feeble tremors occurred.—After death, rigor had not commenced at 36 min.
246.	3 lbs.	0·42	0·2	0·2	Death, in 24 min. after the administration of physostigma.	*With physostigma*, in 3 min., dilatation from $\frac{9}{50} \times \frac{3}{50}$ to $\frac{10}{50} \times \frac{9}{50}$. *After atropia*, the size was in 2 min. $\frac{7}{50} \times \frac{6}{50}$; in 4 min., $\frac{5}{50} \times \frac{4}{50}$; and in 19 min., $\frac{5}{50} \times \frac{4}{50}$.—After death, it was in 1 min., $\frac{4}{50} \times \frac{3}{50}$; in 11 min., $\frac{5}{50} \times \frac{4}{50}$; and in 54 min., $\frac{6}{50} \times \frac{5}{50}$.	*With physostigma*, in 3 min. 30 sec., slowing from 37 to 22 per 10 sec. *After atropia*, the rate per 10 sec. was in 6 min., 19; in 7 min., 14; in 8 min., 46; in 10 min., 58; in 12 min., 45; in 14 min., 16; in 16 min., 30; and in 18 min., 24.	*With physostigma*, in 4 min., slowing from 24 to 22 per 10 sec. *After atropia*, in 3 min., the rate per 10 sec. was 19; but the movements soon after became greatly obstructed by mucus; and from 7 min. until death, they consisted of gasps, which were of very irregular occurrence.	*With physostigma*, none. *After atropia*, in 4 min., the secretion of certain buccal glands was increased; and in 12 min., salivation occurred. There was no defæcation nor urination.	*With physostigma*, in 1 min. 10 sec., slight and infrequent fibrillary twitches; in 3 min. 40 sec., uneasy movements; and in 4 min. 30 sec., extension of the limbs. *After atropia*, the fibrillary twitches soon became pretty well marked, and they continued for several minutes after death. In 2 min., distinct paralysis; and in 6 min., general flaccidity. Tremors frequently occurred.—Rigor began to set in at about 1 hour after death (temp. of laboratory, 68° F.).

SERIES III.—DETERMINATION OF THE LIMITS OF ANTAGONISM WHEN THE DOSE OF PHYSOSTIGMA IS CONSTANT (ONE AND A HALF TIMES THE MINIMUM-LETHAL DOSE), WHILE THE DOSE OF ATROPIA AND THE INTERVAL OF TIME BETWEEN THE ADMINISTRATION OF THE TWO SUBSTANCES VARY.

TABLE 1.—Experiments in which Atropia and Physostigma were administered simultaneously.

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
247.	3 lbs.	0·02	0·02	0·18	Death, in 49 min. after the commencement of the experiment.	*Before the experiment*, the size was $\frac{11}{50} \times \frac{10}{50}$. *After atropia and physostigma*, the size was in 3 min., $\frac{11}{50} \times \frac{10}{50}$; in 7 min., $\frac{15}{50} \times \frac{15}{50}$; in 14 min., $\frac{17}{50} \times \frac{17}{50}$; in 27 min., $\frac{14}{50} \times \frac{14}{50}$; in 35 min., $\frac{10}{50} \times \frac{10}{50}$; and in 48 min., $\frac{10}{50} \times \frac{10}{50}$.—After death, it was in 4 min., $\frac{10}{50} \times \frac{10}{50}$; in 18 min., $\frac{10}{50} \times \frac{10}{50}$; and in 1 hour, $\frac{11}{50} \times \frac{10}{50}$.	*Before the experiment*, the rate was 39 per 10 sec. *After atropia and physostigma*, the rate per 10 sec. was in 2 min., 39; in 5 min., 45; in 7 min., 33; in 27 min., 28; in 32 min., 30; in 37 min., 23; in 44 min., 19; and in 46 min., 21.	*Before the experiment*, the rate was 21 per 10 sec. *After atropia and physostigma*, the rate per 10 sec. was in 4 min., 17; in 23 min., 22; in 27 min., 13; in 32 min; 6; and in 37 min., 4. Afterwards, only gasps occurred irregularly until death.	— *After atropia and physostigma*, in 7 min., slight increase of the secretion of certain buccal glands, which ceased in a few minutes. In 23 min. and 37 min., several normal fæcal pellets were passed. There was neither urination nor salivation.	— *After atropia and physostigma*, in 1 min., infrequent fibrillary twitches, which soon became well marked, but nearly ceased shortly before death. In 7 min., extension of the limbs; in 14 min., slight paralysis; and in 25 min., general flaccidity. Feeble tremors occurred frequently. — Rigor began to set in at about 1 hour after death (temp. of laboratory, 60° F.).
248.	3 lbs.	0·02	0·02	0·18	Death, in 30 min. 30 sec. after the commencement of the experiment.	*Before the experiment*, the size was $\frac{15}{50} \times \frac{14}{50}$. *After atropia and physostigma*, the size was in 4 min., $\frac{16}{50} \times \frac{15}{50}$; in 8 min., $\frac{17}{50} \times \frac{16}{50}$; in 12 min., $\frac{11}{50} \times \frac{11}{50}$; in 15 min., $\frac{7}{50} \times \frac{6}{50}$; in 27 min., $\frac{6}{50} \times \frac{5}{50}$; in 28 min., $\frac{11}{50} \times \frac{11}{50}$; and in 29 min., $\frac{11}{50} \times \frac{10}{50}$.—After death, it was in 1 min., $\frac{9}{50} \times \frac{8}{50}$; in 3 min., $\frac{10}{50} \times \frac{10}{50}$; and in 17 min., $\frac{11}{50} \times \frac{10}{50}$.	*Before the experiment*, the rate was 40 per 10 sec. *After atropia and physostigma*, the rate per 10 sec. was in 3 min., 41; in 5 min., 45; in 7 min., 37; in 10 min., 32; in 12 min., 28; in 14 min., 16; in 17 min., 18; and in 21 min., 20. Afterwards, the cardiac impulse was indistinguishable.	*Before the experiment*, the rate was 20 per 10 sec. *After atropia and physostigma*, the rate per 10 sec. was in 2 min., 17; in 4 min., 21; in 11 min., 17; in 14 min., 8; in 21 min., 16; and in 27 min., 9. Afterwards, only gasps occurred irregularly until death.	— *After atropia and physostigma*, in 10 min., several normal fæcal pellets; in 17 min., salivation; and in 22 min., increased lachrymation.	— *After atropia and physostigma*, in 3 min., slight fibrillary twitches, which soon became well marked, and continued until more than 10 min. after death. In 9 min., slight paralysis; and in 12 min., general flaccidity.

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
249. *a* [Experiment *b* was performed seven days after experiment *a*.]	3 lbs.	0·05	0·05	0·18	Recovery.	*Before the experiment*, the size was $\frac{10}{50} \times \frac{9}{50}$. *After atropia and physostigma*, the size was in 6 min., $\frac{15}{50} \times \frac{16}{50}$; in 17 min., $\frac{10}{50} \times \frac{16}{50}$; in 23 min., $\frac{14}{50} \times \frac{14}{50}$; and in 2 hours, $\frac{15}{50} \times \frac{15}{50}$.—On the 3d day, it was $\frac{13}{50} \times \frac{12}{50}$.	*Before the experiment*, the rate was 37 per 10 sec. *After atropia and physostigma*, the rate per 10 sec. was in 3 min., 46; in 6 min., 41; in 47 min., 50; in 1 hour 10 min., 48; and in 1 hour 50 min., 44.—On the 3d day, it was 37.	*Before the experiment*, the rate was 14 per 10 sec. *After atropia and physostigma*, the rate per 10 sec. was in 17 min., 18; in 23 min., 15; in 47 min., 11; in 1 hour 9 min., 13; and in 1 hour 52 min., 15.—On the 3d day, it was 12.	— *After atropia and physostigma*, in 6 min., slight increase in the secretion of certain buccal glands, which soon ceased. There was no defæcation, urination, nor salivation during the 2 hours of continuous observation.	— *After atropia and physostigma*, in 2 min., slight fibrillary twitches, which soon became very well marked, and continued so for more than 1 hour 30 min. In 16 min., slight weakness; in 40 min., decided paralysis; and in 1 hour 25 min., only slight paralysis. Occasionally feeble tremors occurred.
	b 2 lbs. 15 oz.	0	0	0·12 (= nearly 0·12 gr. p. 3 lbs.)	Death, in 17 min. 30 sec.	—	—	—	—	—
250. *a* [Experiment *b* was performed twelve days after experiment *a*.]	3 lbs. 3 oz.	0·53	0·5	0·19	Recovery.	*Before the experiment*, the size was $\frac{15}{50} \times \frac{11}{50}$. *After atropia and physostigma*, the size was in 1 min., $\frac{14}{50} \times \frac{14}{50}$; in 6 min., $\frac{17}{50} \times \frac{17}{50}$; in 38 min., $\frac{16}{50} \times \frac{16}{50}$; and in 1 hour 40 min., $\frac{14}{50} \times \frac{13}{50}$. —On the following day, it was $\frac{15}{50} \times \frac{14}{50}$; and on the 3d day, $\frac{12}{50} \times \frac{11}{50}$.	*Before the experiment*, the rate was 40 per 10 sec. *After atropia and physostigma*, the rate per 10 sec. was in 2 min., 54; in 19 min., 50; in 28 min., 51; in 46 min., 45; in 1 hour 6 min., 34; and in 1 hour 41 min., 32.—On the following day, it was 35; and on the 3d day, 40.	*Before the experiment*, the rate was 18 per 10 sec. *After atropia and physostigma*, the rate per 10 sec. was in 4 min., 18; in 46 min., 16; in 1 hour 4 min., 17; and in 1 hour 45 min., 15.—On the following day, it was 20; and on the 3d day, 16.	— *After atropia and physostigma*, in 31 min., and several times afterwards, normal fæcal pellets were passed; and in 1 hour 44 min., wet fæces. In 56 min., urine was voided freely. In 1 hour 47 min., the secretion of certain buccal glands was increased, and then the respirations were at times noisy.	— *After atropia and physostigma*, in 2 min., slight fibrillary twitches, which soon became very well marked, and continued so for more than 1 hour 40 min. There was no paralysis until 1 hour 5 min., when the limbs yielded slightly during movements, but this unimportant weakness had not increased at 1 hour 50 min. There were no tremors during the 2 hours of continuous observation.
	b 3 lbs. 4 oz.	0	0	0·13 (= 0·12 gr. p. 3 lbs.)	Death, in 21 min.	—	—	—	—	—
251. *a* [Experiment *b* was performed eleven days after experiment *a*.]	3 lbs. 10 oz.	1·2	1	0·22	Recovery.	*Before the experiment*, the size was $\frac{15}{50} \times \frac{16}{50}$. *After atropia and physostigma*, the size was in 10 min., $\frac{13}{50} \times \frac{13}{50}$; and in 1 hour 20 min., $\frac{18}{50} \times \frac{18}{50}$. —On the following day, it was $\frac{18}{50} \times \frac{18}{50}$; and on the 12th day, $\frac{16}{50} \times \frac{16}{50}$.	*Before the experiment*, the rate was 42 per 10 sec. *After atropia and physostigma*, the rate per 10 sec. was in 2 min., 47; in 5 min., 43; in 9 min., 41; in 25 min., 44; in 40 min., 48; and in 1 hour 20 min., 44.—On the following day, it was 39; and on the 12th day, 39.	*Before the experiment*, the rate was 27 per 10 sec. *After atropia and physostigma*, the rate per 10 sec. was in 9 min., 31; in 26 min., 23; and in 1 hour 19 min., 21.—On the following day, it was 30.	— *After atropia and physostigma*, none. There was no defæcation, urination, nor salivation during the 1 hour 30 min. of continuous observation.	— *After atropia and physostigma*, in 1 min., slight fibrillary twitches, which became very well marked, and continued so for more than 1 hour 20 min. In 13 min., slight paralysis; in 17 min., well-marked paralysis; and in 1 hour 20 min., only slight paralysis. Tremors occurred frequently, and occasionally there were some feeble spasms.
	b 3 lbs. 12 oz.	0	0	0·15 (= 0·12 gr. p. 3 lbs.)	Death, in 29 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
252. *a* [Experiment *b* was performed eleven days after experiment *a*.]	3 lbs. 3 oz.	1·6	1·5	0·19	Recovery.	*Before the experiment*, the size was $\frac{13}{50} \times \frac{12}{50}$. *After atropia and physostigma*, the size was in 1 min., $\frac{14}{50} \times \frac{14}{50}$; in 14 min., $\frac{17}{50} \times \frac{17}{50}$; and in 2 hours 10 min., $\frac{17}{50} \times \frac{17}{50}$.—On the following day, it was $\frac{17}{50} \times \frac{17}{50}$; and on the 12th day, $\frac{14}{50} \times \frac{14}{50}$.	*Before the experiment*, the rate was 43 per 10 sec. *After atropia and physostigma*, the rate per 10 sec. was in 2 min., 54; in 4 min., 43; in 10 min., 51; in 35 min., 51; in 1 hour 25 min., 42; and in 2 hours 10 min., 42.—On the following day, it was 31; on the 4th day, 38; and on the 12th day, 39.	*Before the experiment*, the rate was 30 per 10 sec. *After atropia and physostigma*, the rate per 10 sec. was in 5 min., 24; in 15 min., 32; in 52 min., 26; and in 2 hours 11 min., 24.—On the following day, it was 16.	— *After atropia and physostigma*, none. There was no defæcation, urination, nor salivation during the 2 hours 20 min. of continuous observation.	— *After atropia and physostigma*, in 2 min., slight fibrillary twitches, which soon became more marked, but again became only slight after 27 min. In 15 min., slight paralysis; in 19 min., well-marked paralysis; and in 2 hours 10 min., only slight paralysis. There were no distinct tremors.
	b 3 lbs. 2 oz.	0	0	0·13 (= 0·12 gr. p. 3 lbs.)	Death, in 34 min.	—	—	—	—	—
253. *a* [Experiment *b* was performed nine days after experiment *a*.]	3 lbs.	2	2	0·18	Recovery.	*Before the experiment*, the size was $\frac{14}{50} \times \frac{13}{50}$. *After atropia and physostigma*, the size was in 2 min., $\frac{17}{50} \times \frac{17}{50}$; and in 2 hours 5 min., $\frac{17}{50} \times \frac{17}{50}$.—On the following day, it was $\frac{18}{50} \times \frac{18}{50}$; and on the 10th day, $\frac{18}{50} \times \frac{18}{50}$.	*Before the experiment*, the rate was 42 per 10 sec. *After atropia and physostigma*, the rate per 10 sec. was in 7 min., 46; in 1 hour, about 50; and in 2 hours 10 min., about 50.—On the following day, it was 34; and on the 6th day, 41.	*Before the experiment*, the rate was 19 per 10 sec. *After atropia and physostigma*, the rate per 10 sec. was in 4 min., 16; in 12 min., 19; and in 2 hours 9 min., 16. — On the following day, it was 14; and on the 6th day, 19.	— *After atropia and physostigma*, none. There was no defæcation, urination, nor salivation during the 2 hours 30 min. of continuous observation.	— *After atropia and physostigma*, in 1 min. 30 sec., slight fibrillary twitches, which soon became very well marked, and continued so for more than 2 hours. In 13 min., slight paralysis; in 35 min., well-marked paralysis; and in 2 hours, almost no paralysis. Occasionally, feeble tremors occurred.
	b 3 lbs.	0	0	0·12	Death, in 46 min.	—	—	—	—	—
254. *a* [Experiment *b* was performed eleven days after experiment *a*.]	3 lbs. 4 oz.	2·7	2·5	0·19	Recovery.	*Before the experiment*, the size was $\frac{10}{50} \times \frac{9}{50}$. *After atropia and physostigma*, the size was in 6 min., $\frac{15}{50} \times \frac{15}{50}$; in 45 min., $\frac{16}{50} \times \frac{16}{50}$; and in 2 hours, $\frac{16}{50} \times \frac{16}{50}$.—On the following day it was $\frac{16}{50} \times \frac{16}{50}$.	*Before the experiment*, the rate was 40 per 10 sec. *After atropia and physostigma*, the rate per 10 sec. was in 4 min., 50; in 8 min., 46; in 24 min., 53; in 44 min., 59; in 1 hour 54 min., 47; and in 2 hours 34 min., 38.—On the following day, it was 28; on the 3d day, 35; and on the 12th day, 41.	*Before the experiment*, the rate was 23 per 10 sec. *After atropia and physostigma*, the rate per 10 sec. was in 6 min., 18; in 22 min., 26; in 44 min., 18; and in 2 hours 35 min., 17.—On the following day it was 21.	— *After atropia and physostigma*, in 43 min., in 1 hour, in 1 hour 21 min., and in 2 hours 34 min., several normal fæcal pellets were passed; and in 54 min., urine was voided. There was no salivation.	— *After atropia and physostigma*, in 2 min., slight fibrillary twitches, which soon became well marked, and continued so for more than 2 hours 30 min. In 20 min., slight paralysis; in 30 min., well-marked paralysis; and in 1 hour 50 min., only slight paralysis.
	b 3 lbs. 6 oz.	0	0	0·17 (= 0·15 gr. p. 3 lbs.)	Death, in 31 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
255. *a* [Experiment *b* was performed thirteen days after experiment *a*.]	3 lbs.	3·	3·	0·18	Recovery.	*Before the experiment*, the size was $\frac{14}{50} \times \frac{13}{50}$. *After atropia and physostigma*, the size was in 2 min., $\frac{16}{50} \times \frac{16}{50}$; and in 5 min., $\frac{17}{50} \times \frac{17}{50}$.—On the following day, it was $\frac{16}{50} \times \frac{16}{50}$; on the 3d day, $\frac{15}{50} \times \frac{15}{50}$; and on the 4th day, $\frac{14}{50} \times \frac{14}{50}$.	*Before the experiment*, the rate was 38 per 10 sec. *After atropia and physostigma*, the rate per 10 sec. was in 2 min., 43; in 18 min., 48; in 50 min., 38; in 1 hour 17 min., 32; and in 1 hour 30 min., 32.—On the following day, it was 35; on the 3d day, 39; and on the 4th day, 40.	*Before the experiment*, the rate was 19 per 10 sec. *After atropia and physostigma*, the rate per 10 sec. was in 8 min., 24; in 10 min., 20; in 18 min., 14; and in 1 hour 18 min., 13.—On the following day, it was 20.	— *After atropia and physostigma*, none. There was no defæcation, urination, nor salivation during the 1 hour and 40 min. of continuous observation.	— *After atropia and physostigma*, in 2 min., infrequent fibrillary twitches, which soon became very well marked, but had greatly diminished at 1 hour 30 min. In 9 min., slight paralysis; in 16 min., very well-marked paralysis; and in 1 hour 30 min., pretty well-marked paralysis. Tremors occurred frequently, and feeble spasms occasionally.
b	3 lbs. 2 oz.	0	0	0·13 (= nearly 0·12 gr. p. 3 lbs.)	Death, in 17 min.	—	—	—	—	—
256. *a* [Experiment *b* was performed ten days after experiment *a*.]	3 lbs.	3·3	3·3	0·18	Recovery.	*Before the experiment*, the size was $\frac{11}{50} \times \frac{10}{50}$. *After atropia and physostigma*, the size was in 2 min., $\frac{15}{50} \times \frac{15}{50}$; in 20 min., $\frac{15}{50} \times \frac{15}{50}$; and in 2 hours, $\frac{15}{50} \times \frac{15}{50}$.—On the following day, it was $\frac{15}{50} \times \frac{15}{50}$; and on the 11th day, $\frac{11}{50} \times \frac{10}{50}$.	*Before the experiment*, the rate was 40 per 10 sec. *After atropia and physostigma*, the rate per 10 sec. was in 1 min. 30 sec., 47; in 4 min., 48; in 7 min., 44; in 17 min., 42; in 1 hour, 44; in 1 hour 40 min., 38; and in 1 hour 50 min., 31.—On the following day, it was 31; and on the 3d day, 41.	*Before the experiment*, the rate was 18 per 10 sec. *After atropia and physostigma*, the rate per 10 sec. was in 11 min., 16; in 30 min., 13; in 50 min., 11; and in 1 hour 40 min., 13.—On the following day, it was 14; and on the 3d day, 17.	— *After atropia and physostigma*, in 12 min., urine was voided. There was no defæcation nor salivation during the 2 hours and 30 min. of continuous observation.	— *After atropia and physostigma*, in 1 min. 10 sec., infrequent fibrillary twitches, which soon became well marked, but were again only slight at 45 min. In 8 min., slight paralysis; in 25 min., very well-marked paralysis; and in 2 hours, only slight paralysis. Tremors occurred frequently, and latterly there were some spasmodic movements.
b	3 lbs. 1 oz.	0	0	0·12	Death, in 28 min.	—	—	—	—	—
257.	3 lbs. 6 oz.	3·93	3·5	0·2	Death, in 1 hour 56 min. after the commencement of the experiment.	*Before the experiment*, the size was $\frac{11}{50} \times \frac{10}{50}$. *With atropia and physostigma*, the size was in 1 min., $\frac{15}{50} \times \frac{15}{50}$; in 3 min., $\frac{16}{50} \times \frac{16}{50}$; in 33 min., $\frac{17}{50} \times \frac{17}{50}$; in 1 hour 20 min., $\frac{18}{50} \times \frac{18}{50}$; and in 1 hour 54 min., $\frac{18}{50} \times \frac{18}{50}$.—After death, it was in 1 min., $\frac{16}{50} \times \frac{16}{50}$; in 4 min., $\frac{15}{50} \times \frac{15}{50}$; in 16 min., $\frac{10}{50} \times \frac{11}{50}$; and in 20 min., $\frac{12}{50} \times \frac{12}{50}$.	*Before the experiment*, the rate was 43 per 10 sec. *After atropia and physostigma*, the rate per 10 sec. was in 2 min., 52; in 4 min., 48; in 6 min., 46; in 15 min., 47; in 20 min., 55; in 35 min., 48; in 58 min., 47; in 1 hour 52 min., 52; and in 1 hour 53 min., 51 (impulse now very weak).	*Before the experiment*, the rate was 18 per 10 sec. *After atropia and physostigma*, the rate per 10 sec. was in 4 min., 22; in 8 min., 26; in 12 min., 17; in 33 min., 20; in 57 min., 17; in 1 hour 6 min., 10; and in 1 hour 53 min., 2. Afterwards, feeble respiratory movements occurred infrequently and irregularly until death.	— *After atropia and phgsostigma*, in 20 min., urine was freely voided. There was no defæcation nor salivation.	— *After atropia and physostigma*, in 3 min., infrequent fibrillary twitches, which became pretty well marked, but had altogether disappeared about 1 hour before death. In 18 min., distinct paralysis; and in 58 min., general flaccidity. Tremors occurred frequently, and shortly before death there were some spasmodic movements.—Rigor had not commenced at 29 min. after death.

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
258.	3 lbs.	4	4	0·18	Death, in 49 min. after the commencement of the experiment.	*Before the experiment*, the size was $\frac{8}{50} \times \frac{7}{50}$. *After atropia and physostigma*, the size was in 4 min., $\frac{14}{50} \times \frac{15}{50}$; in 46 min., $\frac{14}{50} \times \frac{14}{50}$; and in 48 min., $\frac{14}{50} \times \frac{14}{50}$.—After death, it was in 1 min., $\frac{14}{50} \times \frac{14}{50}$; in 4 min., $\frac{12}{50} \times \frac{12}{50}$; and in 42 min., $\frac{12}{50} \times \frac{12}{50}$.	*Before the experiment*, the rate was 36 per 10 sec. *After atropia and physostigma*, the rate per 10 sec. was in 3 min., 49; in 29 min., 61; in 34 min., 59; in 40 min., 34; and in 46 min., 20.	*Before the experiment*, the rate was 33 per 10 sec. *After atropia and physostigma*, the rate per 10 sec. was in 6 min., 29; in 17 min., 17; in 32 min., 10; and in 37 min., 3. Soon afterwards, only feeble gasps occurred irregularly.	— *After atropia and physostigma*, none.	— *After atropia and physostigma*, in 3 min., infrequent fibrillary twitches, which became pretty well marked, and then altogether disappeared shortly before death. In 12 min., distinct paralysis; and in 27 min., general flaccidity. Tremors and feeble spasms occurred frequently.—Rigor commenced to set in at about 42 min. after death (temp. of laboratory, 56° F.).
259.	3 lbs.	4·5	4·5	0·18	Death, in 1 hour 5 min. after the commencement of the experiment.	*Before the experiment*, the size was $\frac{12}{50} \times \frac{11}{50}$. *After atropia and physostigma*, the size was in 3 min., $\frac{15}{50} \times \frac{15}{50}$; in 14 min., $\frac{16}{50} \times \frac{16}{50}$; and in 1 hour, $\frac{16}{50} \times \frac{16}{50}$.—After death, it was in 3 min., $\frac{15}{50} \times \frac{15}{50}$; in 11 min., $\frac{13}{50} \times \frac{13}{50}$; in 44 min., $\frac{12}{50} \times \frac{12}{50}$; and in 1 hour 30 min., $\frac{12}{50} \times \frac{12}{50}$.	*Before the experiment*, the rate was 42 per 10 sec. *After atropia and physostigma*, the rate per 10 sec. was in 3 min., 50; in 15 min., 60; in 30 min., 63; in 58 min., 30; and in 1 hour, 47.	*Before the experiment*, the rate was 26 per 10 sec. *After atropia and physostigma*, the rate per 10 sec. was in 10 min., 40; in 20 min. 38; in 25 min., 22; in 29 min., 15; and in 53 min., 10. Afterwards, irregular gasps only occurred.	— *After atropia and physostigma*, in 18 min., urine was voided. There was no defæcation nor salivation.	— *After atropia and physostigma*, in 2 min., rare fibrillary twitches, which continued until nearly 51 min. In 18 min., very slight paralysis; and in 45 min., general flaccidity. Tremors and spasms occurred frequently.—Rigor commenced to set in at about 1 hour 15 min. after death (temperature of laboratory, 58° F.).
260.	3 lbs. 2 oz.	5·2	5	0·187	Death, in 1 hour 35 min. after the commencement of the experiment.	*Before the experiment*, the size was $\frac{12}{50} \times \frac{11}{50}$. *After atropia and physostigma*, the size was in 3 min., $\frac{15}{50} \times \frac{15}{50}$; in 5 min., $\frac{16}{50} \times \frac{16}{50}$; in 57 min., $\frac{17}{50} \times \frac{17}{50}$; and in 1 hour 34 min., $\frac{17}{50} \times \frac{17}{50}$.—After death, it was 2 min., $\frac{17}{50} \times \frac{17}{50}$; in 5 min., $\frac{15}{50} \times \frac{15}{50}$; in 8 min., $\frac{12}{50} \times \frac{12}{50}$; and in 16 min., $\frac{8}{50} \times \frac{8}{50}$.	*Before the experiment*, the rate was 39 per 10 sec. *After atropia and physostigma*, the rate per 10 sec. was in 2 min. 30 sec., 49; in 8 min., 55; in 57 min., 52; in 1 hour 3 min., 48; in 1 hour 30 min., 36; and in 1 hour 32 min., 34.	*Before the experiment*, the rate was 15 per 10 sec. *After atropia and physostigma*, the rate per 10 sec. was in 3 min., 13; in 30 min., 12; in 57 min., 9; and in 1 hour 17 min., 7. In 1 hour 30 min., the respirations became gasping and extremely infrequent and irregular; and they continued so until death.	— *After atropia and physostigma*, in 5 min., urine was voided. There was no defæcation nor salivation.	— *After atropia and physostigma*, in 1 min. 30 sec., rare fibrillary twitches, which altogether ceased at 55 min. In 30 min., distinct paralysis; and in 1 hour 27 min., general flaccidity. Occasionally there was some feeble tremors, and slight spasmodic movements.

TABLE 2.—EXPERIMENTS IN WHICH ATROPIA WAS ADMINISTERED AFTER PHYSOSTIGMA.

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Interval of Time (in minutes).	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respiration.	Effect on Secretion and Excretion.	Effects on Motility, &c.
261.	3 lbs. 6 oz.	0·2	0·05	0·05	10	Death, in 46 min. after the administration of physostigma.	*With physostigma*, in 4 min., dilatation from $\frac{13}{50} \times \frac{12}{50}$ to $\frac{14}{50} \times \frac{14}{50}$; and then in 8 min., contraction to $\frac{13}{50} \times \frac{12}{50}$.	*With physostigma*, in 8 min. 30 sec., slowing from 42 to 26 per 10 sec.	*With physostigma*, in 6 min., acceleration from 26 to 30 per 10 sec.	*With physostigma*, in 7 min., the secretion of certain buccal glands was increased.	*With physostigma*, in 1 min. 30 sec., rare fibrillary twitches, which in 7 min. were general and nearly pretty well marked. In 9 min., extension of the limbs and stumbling movements.
							After atropia, the size was in 1 min., $\frac{11}{50} \times \frac{10}{50}$; in 5 min., $\frac{8}{50} \times \frac{7}{50}$; in 20 min., $\frac{7}{50} \times \frac{6}{50}$; in 35 min., $\frac{7}{50} \times \frac{6}{50}$; and in 36 min., $\frac{10}{50} \times \frac{10}{50}$.—After death, it was in 1 min., $\frac{10}{50} \times \frac{10}{50}$; in 8 min., $\frac{6}{50} \times \frac{6}{50}$; and in 30 min., $\frac{10}{50} \times \frac{10}{50}$.	*After atropia*, the rate per 10 sec. was in 10 min., 28; in 20 min., 24; in 24 min., 30; in 29 min., 36; and in 32 min., 12.	*After atropia*, the rate per 10 sec. was in 8 min., 28; in 16 min., 14 (laboured and noisy); in 22 min., 10; in 28 min., 15 (less impeded); and in 31 min., 9.	*After atropia*, the increased secretion of certain buccal glands became greater, and caused much impediment to respiration. In 32 min., a few fæcal pellets were passed, and a little urine was voided.	*After atropia*, the fibrillary twitches soon became well marked, and continued until after death. In 2 min., distinct paralysis; and in 20 min., general flaccidity. Occasionally, tremors and spasms occurred.
262. [Experiment *b* was performed eight days after experiment *a*.]											
a	2 lbs. 15 oz.	0·17	0·29	0·3	10	Recovery.	*With physostigma*, in 7 min., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{18}{50} \times \frac{18}{50}$.	*With physostigma*, in 6 min., slowing from 45 to 29 per 10 sec.	*With physostigma*, none noted. The original rate was 19 per 10 sec.	*With physostigma*, in 9 min., salivation.	*With physostigma*, in 1 min. 30 sec., fibrillary twitches, which in 9 min. were general and pretty well marked. In 7 min., extension of the limbs.
							After atropia, the size was in 2 min., $\frac{17}{50} \times \frac{17}{50}$; in 6 min., $\frac{18}{50} \times \frac{18}{50}$; in 25 min., $\frac{16}{50} \times \frac{16}{50}$; in 41 min., $\frac{17}{50} \times \frac{17}{50}$; in 1 hour 34 min., $\frac{18}{50} \times \frac{18}{50}$; and in 3 hours 15 min., $\frac{18}{50} \times \frac{18}{50}$.—On the following day, it was $\frac{18}{50} \times \frac{18}{50}$; and on the 3d day, $\frac{15}{50} \times \frac{15}{50}$.	*After atropia*, the rate could not be ascertained on account of the fibrillary twitches until 17 min., when it was 48 per 10 sec. In 1 hour 34 min., it was 54; and in 2 hours 29 min., 52.—On the following day, it was 32.	*After atropia*, the rate per 10 sec. was in 6 min., 35; in 25 min., 23; in 1 hour, 19; in 2 hours 30 min., 13; and in 3 hours 5 min., 13.—On the following day, it was 27.	*After atropia*, the salivation ceased in less than 5 min. There was no defæcation nor urination during the 3 hours 15 min. of continuous observation.	*After atropia*, the fibrillary twitches soon became very well marked, but in 24 min. they were only slight, and remained so until 1 hour 10 min., when they became better marked, and continued so for more than 2 hours. In 4 min., decided paralysis; in 25 min., very decided paralysis; and in 2 hours 20 min., only slight paralysis. Tremors occurred frequently, and occasionally there were some spasmodic movements.
b	3 lbs.	0·12	0	0	—	Death, in 26 min.	—	—	—	—	—

Number of Experiment.		Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Interval of Time (in minutes).	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
263. [Experiment *b* was performed six days after experiment *a*.]	*a*	3 lbs.	0·18	0·5	0·5	10	Recovery.	*With physostigma*, none. The original size was $\frac{15}{50} \times \frac{15}{50}$. *After atropia*, the size was in 2 min., $\frac{17}{50} \times \frac{17}{50}$; in 4 min., $\frac{19}{50} \times \frac{19}{50}$; and in 3 hours, $\frac{19}{50} \times \frac{19}{50}$.—On the following day, it was $\frac{19}{50} \times \frac{19}{50}$; and on the 7th day, $\frac{18}{50} \times \frac{18}{50}$.	*With physostigma*, in 9 min., slowing from 31 to 27 per 10 sec. *After atropia*, the rate per 10 sec. was in 11 min., 57; in 17 min., 61; in 47 min., 63; in 1 hour 15 min., 54; and in 3 hours, 51.—On the following day, it was 27; on the 3d day, 24; and on the 7th day, 34.	*With physostigma*, in 4 min., acceleration from 24 to 27 per 10 sec. *After atropia*, the rate per 10 sec. was in 11 min., 39; in 50 min., 41; in 1 hour 40 min., 28; and in 3 hours, 22.—On the following day, it was 19.	*With physostigma*, in 4 min., increase in the secretion of certain buccal glands. *After atropia*, the above increase ceased in 1 or 2 min. There was no defæcation, urination, nor salivation during the 3 hours 20 min. of continuous observation.	*With physostigma*, in 8 min., pretty general fibrillary twitchings. In 9 min. 30 sec., slight paralysis. *After atropia*, the fibrillary twitchings soon became well marked, and remained nearly so for more than 3 hours. The paralysis did not distinctly increase until 40 min., when it was pretty well marked; and in 2 hours 40 min., it had almost disappeared. Occasionally, tremors and starts occurred; and the latter could be caused by slight excitations.
	b	3 lbs.	0·12	0	0	—	Death, in 19 min.	—	—	—	—	—
264. [Experiment *b* was performed seven days after experiment *a*.]	*a*	3 lbs. 8 oz.	0·21	1·1	1	10	Recovery.	*With physostigma*, in 9 min., dilatation from $\frac{13}{50} \times \frac{13}{50}$ to $\frac{14}{50} \times \frac{14}{50}$. *After atropia*, the size was in 6 min., $\frac{18}{50} \times \frac{18}{50}$; in 20 min., $\frac{17}{50} \times \frac{17}{50}$; and in 2 hours 50 min., $\frac{15}{50} \times \frac{15}{50}$.—On the following day, it was $\frac{14}{50} \times \frac{14}{50}$; and on the 6th day, $\frac{14}{50} \times \frac{13}{50}$.	*With physostigma*, in 9 min. 30 sec., slowing from 46 to 33 per 10 sec. *After atropia*, the rate could not be ascertained on account of the very well-marked fibrillary twitches.—On the following day, it was 39 per 10 sec.; and on the 6th day, 42.	*With physostigma*, none. The original rate was 29 per 10 sec. *After atropia*, the rate per 10 sec. was in 6 min., 33; in 20 min., 37; in 1 hour, 35; and in 2 hours 50 min., 28.—On the following day, it was 39.	*With physostigma*, in 8 min., slight salivation. *After atropia*, the salivation had ceased in 4 min. In 45 min., fæcal pellets were passed, and this was repeated frequently, the fæces being at 2 hours 20 min. of a semi-liquid consistence. In 1 hour, and in 2 hours 40 min., urine was voided.	*With physostigma*, in 9 min. 30 sec., well-marked and general fibrillary twitches. In 6 min., extension of limbs; and in 9 min., slight paralysis, with stumbling movements. *After atropia*, the fibrillary twitches very soon became very well marked, and continued so for more than 2 hours 50 min. In 5 min., distinct paralysis; in 1 hour 40 min., well-marked paralysis; and in 2 hours 20 min., distinct, though diminished, paralysis.
	b	3 lbs. 6 oz.	0·135	0	0	—	Death, in 39 min.	—	—	—	—	—
265. [Experiment *b* was performed seven days after experiment *a*.]	*a*	3 lbs.	0·18	1·5	1·5	10	Recovery.	*With physostigma*, none. The original size was $\frac{12}{50} \times \frac{12}{50}$. *After atropia*, the size was in 3 min., $\frac{16}{50} \times \frac{16}{50}$; in 11 min., $\frac{17}{50} \times \frac{17}{50}$; and in 2 hours 12 min., $\frac{17}{50} \times \frac{17}{50}$.	*With physostigma*, in 6 min., slowing from 51 to 34 per 10 sec. *After atropia*, the rate per 10 sec. was in 30 min., 57; in 1 hour 6 min., 50; and in 2 hours 15 min., 47.—On the following day, it was 45; on the 3d day, 47; and on the 8th day, 41.	*With physostigma*, none noted. The original rate was 47 per 10 sec. *After atropia*, the rate per 10 sec. was in 12 min., 49; in 40 min., 38; in 50 min., 28; and in 2 hours 14 min., 47.—On the following day, it was 23.	*With physostigma*, in 6 min., slight increase of the secretion of certain buccal glands; and in 8 min. 30 sec., passage of normal fæcal pellets. *After atropia*, the above increased in a very few min. In 14 min., several normal fæcal pellets were passed.—There was no urination during the 2 hours 15 min. of continuous observation.	*With physostigma*, in 7 min., pretty well-marked and general fibrillary twitches. In 9 min., some exension of the limbs, and stumbling movements. *After atropia*, the fibrillary twitches soon became very well marked, but they lessened greatly after 30 min. In 6 min., distinct paralysis; in 50 min., well-marked paralysis; and in 2 hours, distinct, though diminished, paralysis. Tremors and spasmodic movements occurred frequently.
	b	3 lbs.	0·18	0	0	—	Death, in 39 min.					

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal	Interval of Time (in minutes.)	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
266. *a* [Experiment *b* was performed nine days after experiment *a*.]	3 lbs. 1 oz.	0·183	2·	2·	10	Recovery.	*With physostigma*, in 8 min., dilatation from $\frac{10}{50}\times\frac{9}{50}$ to $\frac{12}{50}\times\frac{12}{50}$; and in 9 min. 30 sec., contraction to $\frac{9}{50}\times\frac{9}{50}$. *After atropia*, the size was in 6 min., $\frac{17}{50}\times\frac{17}{50}$; in 14 min., $\frac{15}{50}\times\frac{16}{50}$; and in 3 hours, $\frac{15}{50}\times\frac{15}{50}$.—On the following day, it was $\frac{17}{50}\times\frac{17}{50}$; on the 3d day, $\frac{17}{50}\times\frac{17}{50}$; on the 4th day, $\frac{12}{50}\times\frac{12}{50}$; and on the 7th day, $\frac{11}{50}\times\frac{10}{50}$.	*With physostigma*, in 9 min., slowing from 46 to 33 per 10 sec. *After atropia*, the rate per 10 sec. was in 5 min., 57; in 15 min., 65; in 1 hour, 62; and in 3 hours, 59.—On the following day, it was 45; and on the 10th day, 42.	*With physostigma*, none noted. The original rate was 25 per 10 sec. *After atropia*, moist sounds were present for 2 min., and then ceased. The rate per 10 sec. was in 5 min., 27; in 24 min., 18; in 1 hour, 11; in 1 hour 20 min., 16; and in 3 hours 5 min., 17.—On the following day, it was 20.	*With physostigma*, in 9 min. 20 sec., slight salivation and noisy respiration. In 6 min., several pultaceous pellets were passed. *After atropia*, the salivation ceased in 3 or 4 min. In 2 hours 19 min., several small and dry fæcal pellets. There was no urination during the 3 hours 10 min. of continuous observation.	*With physostigma*, in 9 min., pretty well-marked and general fibrillary twitches. In 7 min., extension of the limbs; and in 9 min., slight paralysis. *After atropia*, the fibrillary twitches soon became well marked, they afterwards gradually lessened until in 20 min., they were extremely rare; and in 2 hours, they had altogether ceased. In 5 min., distinct paralysis; in 20 min., very decided paralysis; and in 3 hours, only slight paralysis. Occasionally, somewhat spasmodic movements occurred.
b	3 lbs. 2 oz.	0·18 (= nearly 0·18 gr. p. 3 lbs.)	0	0	—	Death, in 18 min.	—	—	—	—	—
267. *a* [Experiment *b* was performed eleven days after experiment *a*.]	2 lbs. 15 oz.	0·176	2·25	2·3	10	Recovery.	*With physostigma*, in 7 min., dilatation from $\frac{12}{50}\times\frac{11}{50}$ to $\frac{15}{50}\times\frac{14}{50}$. *After atropia*, the size was in 4 min., $\frac{16}{50}\times\frac{16}{50}$; in 8 min., $\frac{13}{50}\times\frac{13}{50}$; in 30 min., $\frac{16}{50}\times\frac{16}{50}$; and in 2 hours 58 min., $\frac{15}{50}\times\frac{15}{50}$.—On the following day, it was $\frac{16}{50}\times\frac{16}{50}$; and on the 12th day, $\frac{11}{50}\times\frac{10}{50}$.	*With physostigma*, in 8 min., slowing from 40 to 29 per 10 sec. *After atropia*, the rate per 10 sec. was in 2 min., 57; in 6 min., 61; in 10 min., 52; in 18 min., 40; in 37 min., 29; in 1 hour 52 min., 37; and in 3 hours, 33.—On the following day, it was 27; and on the 5th day, 43.	*With physostigma*, in 6 min., slowing from 16 to 14 per 10 sec; and in 9 min., occasional moist sounds. *After atropia*, the moist sounds had ceased within 2 min. The rate per 10 sec. was in 7 min., 17; in 11 min., 16; in 2 hours, 14; and in 3 hours, 16.—On the following day, it was 11; on the 6th day, 13; and on the 12th day, 19.	*With physostigma*, in 9 min., slight salivation; and in 8 min., several normal fæcal pellets. *After atropia*, the salivation ceased nearly immediately. In 2 hours 10 min., several normal fæcal pellets were passed. There was no urination during the 3 hours 20 min. of continuous observation.	*With physostigma*, in 9 min., pretty well-marked and general fibrillary twitches. In 5 min., extension of the limbs; and in 8 min., slight paralysis. *After atropia*, the fibrillary twitches became first well marked, then only slightly marked, and again, after 2 hours, well marked. In 10 min., decided paralysis; in 30 min., an almost flaccid condition; and in 3 hours, slight, though distinct, paralysis. Occasionally, feeble tremors and starts occurred.
b	3 lbs. 3 oz.	0·19 (= 0·18 gr. p. 3 lbs.)	0	0	—	Death, in 16 min. 30 sec.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Interval of Time (in minutes).	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
268. *a* [Experiment *b* was performed twelve days after experiment *a*.]	3 lbs. 2 oz.	0·19	2·5	2·4	10	Recovery.	*With physostigma*, in 9 min., dilatation from $\frac{8}{50} \times \frac{7}{50}$ to $\frac{9}{50} \times \frac{8}{50}$. *After atropia*, the size was in 2 min., $\frac{15}{50} \times \frac{15}{50}$; and in 2 hours 20 min., $\frac{16}{50} \times \frac{15}{50}$.—On the following day, it was $\frac{10}{50} \times \frac{9}{50}$; on the 4th day, $\frac{7}{50} \times \frac{6}{50}$; and on the 13th day, $\frac{8}{50} \times \frac{7}{50}$.	*With physostigma*, in 8 min., slowing from 37 to 30 per 10 sec. *After atropia*, the rate per 10 sec. was in 11 min., 57; in 50 min., 52; in 1 hour 25 min., 60; and in 2 hours 30 min., 47.—On the following day, it was 39; on the 4th day, 43; and on the 13th day, 43.	*With physostigma*, in 8 min. 30 sec., slowing from 25 to 29 per 10 sec. *After atropia*, the rate per 10 sec. was in 9 min., 21; in 18 min., 19; in 50 min., 11; in 1 hour 25 min., 18; and in 2 hours 28 min., 21.—On the following day, it was 28.	*With physostigma*, in 5 min., slight increase in the secretion of certain buccal glands. *After atropia*, the above increase soon ceased. There was no defæcation, urination, nor salivation during the 2 hours 40 min. of continuous observation.	*With physostigma*, in 9 min., pretty well-marked and general fibrillary twitches. *After atropia*, the fibrillary twitches were very well marked during the first 10 min.; they then became pretty well-marked, and continued so for more than 2 hours 30 min. In 6 min., distinct paralysis; in 30 min., very decided paralysis; and in 2 hours 30 min., only slight paralysis. Occasionally, tremors occurred, and they could be caused by slight excitation.
b	3 lbs. 6 oz.	0·135 (= 0·12 gr. p. 3 lbs.)	0	0	—	Death, in 31 min.	—	—	—	—	—
269. *a* [Experiment *b* was performed eight days after experiment *a*.]	3 lbs. 5 oz.	0·198	2·76	2·5	10	Recovery.	*With physostigma*, in 9 min., contraction from $\frac{15}{50} \times \frac{15}{50}$ to $\frac{7}{50} \times \frac{6}{50}$. *After atropia*, the size was in 1 min., $\frac{6}{50} \times \frac{5}{50}$; in 4 min., $\frac{14}{50} \times \frac{13}{50}$; in 10 min., $\frac{16}{50} \times \frac{16}{50}$; in 18 min., $\frac{17}{50} \times \frac{17}{50}$; and in 1 hour 15 min., $\frac{16}{50} \times \frac{16}{50}$.—On the following day, it was $\frac{16}{50} \times \frac{16}{50}$; on the 6th day, $\frac{15}{50} \times \frac{14}{50}$; and on the 9th day, $\frac{14}{50} \times \frac{14}{50}$.	*With physostigma*, in 4 min. 30 sec., slowing from 38 to 31 per 10 sec. *After atropia*, the rate per 10 sec. was in 3 min., 58; in 9 min., 60; in 18 min., 64; in 54 min., 49; and in 1 hour 20 min., 43.—On the following day, it was 29; on the 3d day, 24; on the 6th day, 39; and on the 9th day, 40.	*With physostigma*, no change in the rate was noted. The original rate was 23 per 10 sec. In 9 min., moist sounds accompanied the respirations. *After atropia*, the moist sounds had ceased in 4 min. The rate per 10 sec. was in 4 min., 22; in 17 min., 20; in 25 min., 34; in 32 min., 24; and in 1 hour 16 min., 21.—On the following day, it was 16; and on the 3d day, 24.	*With physostigma*, in 8 min. 50 sec., salivation; and in 9 min., several fæcal pellets were passed. *After atropia*, the salivation ceased almost immediately, but it re-appeared in 9 min., and continued until 30 min. No defæcation nor urination occurred during the 1 hour 25 min. of continuous observation.	*With physostigma*, in 9 min., pretty well-marked and general fibrillary twitches. In 6 min., extension of the limbs; and in 9 min. 30 sec., slight paralysis and stumbling movements. *After atropia*, in 6 min., the fibrillary twitches were well marked, but in 15 min. they had almost ceased. In 2 min., decided paralysis; and in 32 min., very decided paralysis, which had not appreciably lessened at 1 hour 25 min. Tremors and starts occurred frequently.
b	3 lbs. 5 oz.	0·19 (= nearly 0.18 gr. p. 3 lbs.)	0	0	—	Death, in 15 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Interval of Time (in minutes).	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
270.	2 lbs. 12 oz.	0·165	2·49	2·7	10	Death, in 42 min. after the administration of physostigma.	*With physostigma*, in 6 min., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{15}{50} \times \frac{14}{50}$.	*With physostigma*, in 9 min., slowing from 41 to 28 per 10 sec.	*With physostigma*, in 5 min., slowing from 14 to 11 per 10 sec.	*With physostigma*, in 4 min, slight increase of the secretion of certain buccal glands.	*With physostigma*, in 9 min. 30 sec., pretty well-marked and general fibrillary twitches. In 6 min. 30 sec., extension of limbs; and in 9 min., stumbling movements.
							After atropia, the size was in 3 min., $\frac{16}{50} \times \frac{16}{50}$; in 9 min., $\frac{18}{50} \times \frac{18}{50}$; and in 31 min. 30 sec., $\frac{18}{50} \times \frac{18}{50}$.—After death, it was in 1 min., $\frac{16}{50} \times \frac{16}{50}$; in 2 min., $\frac{14}{50} \times \frac{14}{50}$; in 5 min., $\frac{10}{50} \times \frac{10}{50}$; in 11 min., $\frac{9}{50} \times \frac{8}{50}$; in 50 min., $\frac{10}{50} \times \frac{10}{50}$; and in 1 hour 20 min., $\frac{10}{50} \times \frac{10}{50}$.	*After atropia*, the rate per 10 sec. was in 2 min., 57; in 11 min., 58; in 21 min., 55; in 26 min., 47; and in 30 min., 34.	*After atropia*, the rate per 10 sec. was in 3 min., 18; in 9 min., 22; in 12 min., 19; in 21 min., 6; in 26 min., 3; and in 28 min., 2. Afterwards, only rare gasps occurred irregularly until death.	*After atropia*, the above increase soon ceased. There was no defæcation, urination, nor salivation.	*After atropia*, the fibrillary twitches became well marked, but were only slight at 11 min., and soon after they ceased. In 3 min., distinct paralysis; and in 20 min., general flaccidity. Frequently, tremors and feeble spasms occurred.—The first appearance of rigor was at 1 hour 20 min. after death (temp. of laboratory, 62° F.).
271.	2 lbs. 15 oz.	0·176	2·93	3	10	Death, in 35 min. after the administration of physostigma.	*With physostigma*, in 9 min., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{13}{50} \times \frac{12}{50}$.	*With physostigma*, in 6 min., slowing from 42 to 31 per 10 sec.	*With physostigma*, in 5 min., acceleration from 23 to 26 per 10 sec.	*With physostigma*, in 9 min., slight salivation.	*With physostigma*, in 9 min. 30 sec., nearly well-marked fibrillary twitches. In 7 min., extension of limbs; and in 9 min., slight paralysis.
							After atropia, the size was in 2 min., $\frac{17}{50} \times \frac{17}{50}$; in 12 min., $\frac{16}{50} \times \frac{16}{50}$; and in 25 min., $\frac{15}{50} \times \frac{15}{50}$.—After death, it was in 2 min., $\frac{13}{50} \times \frac{12}{50}$; in 5 min., $\frac{11}{50} \times \frac{10}{50}$; and in 50 min., $\frac{12}{50} \times \frac{11}{50}$.	*After atropia*, the rate per 10 sec. was in 5 min., 45; in 7 min., 58; in 10 min., 63; in 19 min., 45; in 22 min., 38; and in 23 min. 30 sec., 26.	*After atropia*, the rate per 10 sec. was in 3 min., 33; in 10 min., 24; in 17 min., 16; and in 20 min., 8. Afterwards, infrequent gasps occurred irregularly.	*After atropia*, the salivation ceased almost immediately. In 15 min., urine was freely voided. There was no defæcation.	*After atropia*, the fibrillary twitches were well marked for a few minutes; they then became slight, and afterwards ceased altogether. In 5 min., decided paralysis; and in 20 min., general flaccidity. Some excited movements took place, and, latterly, there were several feeble convulsions.—The first appearance of rigor was at 50 min. after death (temp. of laboratory, 62° F.).

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Interval of Time in (minutes).	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
272. *a*	3 lbs. 7 oz.	0·206	0·34	0·3	14	Recovery.	*With physostigma*, in 10 min., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{16}{50} \times \frac{16}{50}$; and in 13 min. 30 sec., contraction to $\frac{6}{50} \times \frac{6}{50}$.	*With physostigma*, in 13 min. 40 sec., slowing from 40 to 14 per 10 sec.	*With physostigma*, in 13 min., laboured, noisy, and gasping respirations occurred very infrequently and irregularly. The original rate was 23 per 10 sec.	*With physostigma*, in 11 min., saliva was freely escaping, and there was considerable accumulation of fluid in the fauces and air passages. In 13 min., several fæcal pellets were passed.	*With physostigm*, in 11 min., well-marked and general fibrillary twitches. In 5 min. 30 sec., extension of the limbs; in 11 min., distinct paralysis; and in 13 min. 30 sec., very advanced paralysis, the rabbit being flaccid on the side.
	[Experiment *b* was performed six days after experiment *a*.]						*After atropia*, the size was in 5 min., $\frac{9}{50} \times \frac{8}{50}$; in 7 min., $\frac{14}{50} \times \frac{14}{50}$; in 10 min., $\frac{16}{50} \times \frac{16}{50}$; in 26 min., $\frac{15}{50} \times \frac{15}{50}$; in 35 min., $\frac{14}{50} \times \frac{13}{50}$; in 1 hour 21 min., $\frac{12}{50} \times \frac{12}{50}$; and in 3 hours 5 min., $\frac{11}{50} \times \frac{11}{50}$.—On the following day, it was $\frac{14}{50} \times \frac{13}{50}$; and on the 7th day, $\frac{14}{50} \times \frac{13}{50}$.	*After atropia*, the rate per 10 sec. was in 4 min., 54; in 8 min., 62; in 1 hour 8 min., 61; in 2 hours 20 min., 50; and in 3 hours 6 min., 33.—On the following day, it was 31; on the 3d day, 42; and on the 7th day, 42.	*After atropia*, the laboured infrequent gasps continued for about 2 min.; but in 4 min., normal respiratory movements occurred 17 times per 10 sec. The rate per 10 sec. was in 14 min., 17; in 26 min., 18; in 1 hour 8 min., 21; and in 3 hours 4 min., 24. The moist sounds did not cease until 3 hours 4 min.	*After atropia*, in 15 min., the salivation ceased, but reappeared in 1 hour 45 min., and again disappeared in 3 hours; several pultaceous fæcal pellets were passed; and in 3 hours 5 min., a little urine was voided.	*After atropia*, the fibrillary twitches were very well marked until 2 hours, after which they gradually diminished. In 14 min., the rabbit succeeded in turning from the side, and then the paralysis slowly lessened; and at 2 hours, the rabbit was in a normal sitting posture.
b	3 lbs. 8 oz.	0·21 (= 0·18 gr. p. 3 lbs.)	0	0	—	Death, in 23 min.	—	—	—	—	—
273. *a*	3 lbs. 7 oz.	0·206	0·34	0·3	15	Recovery.	*With physostigma*, in 7 min., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{14}{50} \times \frac{14}{50}$; and in 14 min., contraction to $\frac{8}{50} \times \frac{7}{50}$.	*With physostigma*, in 14 min. 30 sec., slowing from 40 to 21 per 10 sec.	*With physostigma*, in 12 min., slowing from 40 to 34 per 10 sec.; and in 14 min., laboured and noisy respirations.	*With physostigma*, in 14 min., saliva was freely escaping, and there was considerable accumulation of fluid in the fauces and air passages.	*With physostigma*, in 12 min., pretty well-marked and general fibrillary twitches. In 8 min., extension of the limbs; and in 14 min., very decided paralysis.
	[Experiment *b* was performed six days after experiment *a*.]						*After atropia*, the size was in 6 min., $\frac{17}{50} \times \frac{17}{50}$; in 1 hour 35 min., $\frac{18}{50} \times \frac{18}{50}$; and in 2 hours 30 min., $\frac{18}{50} \times \frac{18}{50}$.—On the following day, it was $\frac{18}{50} \times \frac{18}{50}$; on the 3d day, $\frac{13}{50} \times \frac{13}{50}$; and on the 6th day, $\frac{12}{50} \times \frac{12}{50}$.	*After atropia*, the rate per 10 sec. was in 5 min. 30 sec., 54; in 20 min., 63; and in 1 hour 36 min., 61.—On the following day, it was 28; on the 3d day, 35; and on the 6th day, 38.	*After atropia*, the rate per 10 sec. was in 4 min., 20; in 38 min., 28; and in 2 hours 32 min., 35. The moist sounds disappeared at about 12 min., but they reappeared at 1 hour 35 min.—On the following day, the rate was 35 per 10 sec.	*After atropia*, in 12 min., the salivation ceased, and it did not recur. There was no defæcation nor urination during the 2 hours 40 min. of continuous observation.	*After atropia*, the fibrillary twitches soon became very well marked, and they continued so for more than 2 hours 35 min. In 12 min., the paralysis had distinctly lessened; but it was still marked at 2 hours 40 min. Neither tremors nor spasms occurred.
b	3 lbs. 9 oz.	0·21 (= 0·18 gr. nearly p. 3 lbs.)	0	0	—	Death, in 17 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Interval of Time (in minutes).	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
274. *a*	3 lbs. 4 oz.	0·195	0·56	0·5	15	Recovery.	*With physostigma*, in 10 min., dilatation from $\frac{14}{50} \times \frac{14}{50}$ to $\frac{15}{50} \times \frac{15}{50}$; and in 14 min. 30 sec., contraction to $\frac{10}{50} \times \frac{10}{50}$.	*With physostigma*, in 7 min., slowing from 46 to 38 per 10 sec. Afterwards, the rate could not be ascertained on account of the fibrillary twitches, and the tremors and struggles that were excited when the hand was placed on the thorax.	*With physostigma*, in 14 min., laboured, noisy, and impeded respirations occurred infrequently. The original rate was 25 per 10 sec.	*With physostigma*, in 9 min., saliva was freely escaping. In 8 min., several normal fæcal pellets were passed; and in 14 min., wet and pultaceous fæces.	*With physostigma*, in 8 min., well-marked and general fibrillary twitches. In 6 min., extension of the limbs; in 11 min., decided paralysis; and in 14 min. 30 sec., general flaccidity. In 9 min., tremors occurred; and in 14 min., there were some very feeble spasmodic movements.
		[Experiment *b* was performed six days after experiment *a*.]					*After atropia*, the size was in 2 min., $\frac{9}{50} \times \frac{9}{50}$; in 4 min., $\frac{14}{50} \times \frac{14}{50}$; in 10 min., $\frac{17}{50} \times \frac{17}{50}$; and in 2 hours 40 min., $\frac{18}{50} \times \frac{18}{50}$.—On the following day, it was $\frac{18}{50} \times \frac{18}{50}$; on the 4th day, $\frac{16}{50} \times \frac{16}{50}$; and on the 7th day, $\frac{16}{50} \times \frac{16}{50}$.	*After atropia*, the rate per 10 sec. was in 38 min., 64; and in 1 hour 20 min., 64.—On the following day, it was 44; and on the 7th day, 44.	*After atropia*, the rate per 10 sec. was in 5 min., 20; in 7 min., 15; in 11 min., 12; in 27 min., 16; in 1 hour 22 min., 22; and in 2 hours 40 min., 16. The moist sounds lessened after 1 hour 40 min., and soon afterwards they ceased.	*After atropia*, in about 38 min., the salivation ceased, and it did not recur. In 2 hours, a large number of normal fæcal pellets were passed. There was no urination during the 2 hours 40 min. of continuous observation.	*After atropia*, in 30 min., the fibrillary twitches were only pretty well marked, and they continued so for more than 2 hours. The paralysis did not appreciably diminish until 1 hour 30 min., but in 2 hours there were only slight paralysis. Neither tremors nor spasms occurred.
b	3 lbs. 6 oz.	0·13 (= 0.12 gr. p. 3 lbs.)	0	0	—	Death, in 19 min.	—	—	—	—	—
275. *a*	3 lbs.	0·18	1	1	15	Recovery.	*With physostigma*, in 6 min. 30 sec., dilatation from $\frac{15}{50} \times \frac{15}{50}$ to $\frac{16}{50} \times \frac{16}{50}$; and in 10 min., contraction to $\frac{5}{50} \times \frac{4}{50}$.	*With physostigma*, in 13 min., slowing from 42 to 18 per 10 sec.	*With physostigma*, in 14 min., slowing from 39 to 16 per 10 sec. In 10 min., the respirations became noisy, and in 14 min., noisy and laboured.	*With physostigma*, in 9 min. 30 sec., saliva was escaping. In 10 min., several fæcal pellets were passed.	*With physostigma*, in 14 min., well-marked and general fibrillary twitches. In 6 min., extension of the limbs; and in 13 min. 20 sec., general flaccidity, with the animal lying on the side.
		[Experiment *b* was performed seven days after experiment *a*.]					*After atropia*, the size was in 2 min., $\frac{5}{50} \times \frac{4}{50}$; in 5 min., $\frac{7}{50} \times \frac{6}{50}$; in 9 min., $\frac{11}{50} \times \frac{11}{50}$; in 12 min., $\frac{14}{50} \times \frac{14}{50}$; in 25 min., $\frac{10}{50} \times \frac{10}{50}$; and in 1 hour 20 min., $\frac{11}{50} \times \frac{11}{50}$.—On the following day, it was $\frac{16}{50} \times \frac{16}{50}$; on the 6th day, $\frac{15}{50} \times \frac{15}{50}$; and on the 8th day, $\frac{13}{50} \times \frac{13}{50}$.	*After atropia*, the rate per 10 sec. was in 2 min., 46; in 7 min., 58; in 14 min., 62; in 23 min., 42; in 47 min., 42; and in 1 hour 11 min., 42.—On the following day, it was 50; on the 3d day, 42; and on the 8th day, 43.	*After atropia*, the rate per 10 sec. was in 3 min., 9; in 13 min., 8; in 30 min., 7; in 1 hour, 9; and in 1 hour 10 min., 16. The moist sounds ceased in 13 min., but reappeared, though for only 10 min., in 1 hour. The respirations were extremely feeble until 1 hour.—On the 2d day, the rate per 10 sec. was 23.	*After atropia*, the salivation ceased in a few min., but it reappeared in a slight form at 50 min.; and again ceased at 1 hour 10 min. In 45 min., several fæcal pellets were passed. There was no urination during the 1 hour 20 min. of continuous observation.	*After atropia*, the fibrillary twitches were very well marked for 10 min.; they were then extremely slight for about 40 min.; but in 1 hour 10 min., they were again well marked. The condition of general flaccidity did not appreciably improve until 52 min., after which the animal turned from the side; but even at 1 hour 15 min., there was very well marked paralysis. Neither tremors nor spasms occurred during the 1 hour 20 min. of continuous observation.
b	3 lbs. 2 oz.	0·18 (= nearly 0·18 gr. p. 3 lbs.)	0	0	—	Death, in 18 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Interval of Time (in minutes).	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
276.	3 lbs.	0·18	1·5	1·5	15	Death, in 1 hour 12 min. after the administration of physostigma.	*With physostigma*, in 7 min., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{15}{50} \times \frac{14}{50}$; and in 14 min., contraction to $\frac{10}{50} \times \frac{9}{50}$. *After atropia*, the size was in 2 min., $\frac{15}{50} \times \frac{15}{50}$; in 18 min., $\frac{16}{50} \times \frac{16}{50}$; and in 57 min., $\frac{16}{50} \times \frac{15}{50}$.—After death, it was in 2 min., $\frac{14}{50} \times \frac{14}{50}$; in 10 min., $\frac{9}{50} \times \frac{9}{50}$; and in 33 min., $\frac{10}{50} \times \frac{10}{50}$.	*With physostigma*, in 13 min., slowing from 42 to 19 per 10 sec. *After atropia*, the rate per 10 sec. was in 4 min., 49; in 29 min., 60; in 53 min., 41; and in 56 min., 40.	*With physostigma*, in 9 min., slowing from 30 to 26 per 10 sec. In 11 min., the respirations became noisy; and in 14 min., noisy and laboured. *After atropia*, the rate per 10 sec. was in 3 min., 22; in 10 min., 20; in 28 min., 20; and in 50 min., 5. Afterwards only feeble gasps occurred infrequently and irregularly. The moist sounds diminished in 10 min., and they altogether ceased in 25 min.	*With physostigma*, in 13 min., saliva was escaping from the mouth, and several fæcal pellets were passed. *After atropia*, the salivation altogether ceased in 4 min. In 45 min., urine was voided; but there was no defæcation.	*With physostigma*, in 9 min., pretty well marked and general fibrillary twitches. In 6 min., extension of the limbs; and in 14 min., very advanced paralysis. *After atropia*, the fibrillary twitches were well marked for 10 min.; they then diminished; and they finally ceased at 48 min. In 2 min., the paralysis was lessened and remained so for 12 min.; in 45 min., it was again very decided; and in 46 min., the condition was one of general flaccidity. There were no tremors, but some irregular and feeble spasms occurred.—There was no appearance of rigor at 33 min. after death.
277.	3 lbs.	0·18	2	2	15	Death, in 45 min. after the administration of physostigma.	*With physostigma*, in 5 min., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{15}{60} \times \frac{14}{60}$; and in 14 min. 30 sec., contraction to $\frac{8}{50} \times \frac{8}{50}$. *After atropia*, the size was in 4 min., $\frac{17}{60} \times \frac{17}{60}$; in 24 min., $\frac{10}{50} \times \frac{10}{50}$; and in 30 min. (moment of death), $\frac{10}{50} \times \frac{10}{50}$.—After death, it was in 3 min., $\frac{12}{50} \times \frac{12}{50}$; in 7 min., $\frac{10}{50} \times \frac{10}{50}$; and in 57 min., $\frac{13}{50} \times \frac{13}{50}$.	*With physostigma*, in 14 min., slowing from 41 to 19 per 10 sec. *After atropia*, the rate per 10 sec. was in 2 min., 52; and in 28 min., 52.	*With physostigma*, in 5 min. 30 sec., acceleration from 22 to 31 per 10 sec. In 14 min., the respirations were noisy, laboured, and infrequent. *After atropia*, in 24 min., the respirations were gasping, and at the rate of only 5 per 10 sec.; and in 29 min. 30 sec., only 2 gasps occurred per 10 sec. The moist sounds altogether ceased in a few minutes.	*With physostigma*, in 7 min., saliva was escaping from the mouth. *After atropia*, the salivation altogether ceased in a few minutes. In 4 min., urine was freely and copiously voided. There was no defæcation.	*With physostigma*, in 13 min., well-marked and general fibrillary twitches. In 7 min., extension of the limbs; and in 14 min., very advanced paralysis. *After atropia*, the fibrillary twitches continued well marked for 11 min.; they afterwards became slight, and remained so for a few min. after death. In 23 min., general flaccidity was present. Occasionally, tremors occurred.—Rigor first began to set in at 57 min. after death (temp. of laboratory, 58° F.).

Number of Experiment.	Weight of Rabbit.	sostigma (in Grains). Actual Dose of Sul. of Physostigmia.	phate of Atropia (in Grains). Actual Dose.	Dose p. 3 lbs. of Animal.	Interval of Time (in minutes).	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
278.	3 lbs. 8 oz.	0·21	0·32	0·3	17	Death, in 39 min. after the administration of physostigma.	*With physostigma*, in 6 min., dilatation from $\frac{11}{50} \times \frac{10}{50}$ to $\frac{15}{50} \times \frac{15}{50}$; and in 14 min. 30 sec., contraction to $\frac{5}{50} \times \frac{4}{50}$.	*With physostigma*, in 16 min. 30 sec., slowing from 40 to 11 per 10 sec.	*With physostigma*, in 16 min., the respirations were very laboured, impeded by mucus, infrequent, and gasping.	*With physostigma*, in 14 min., saliva was escaping from the mouth.	*With physostigma*, in 12 min., pretty well-marked fibrillary twitches, which were only slight at 16 min. In 6 min., extension of the limbs; in 10 min., decided paralysis; and in 15 min., general flaccidity, the animal lying on the side. Latterly, some tremors occurred.
							After atropia, the size was in 2 min, $\frac{5}{50} \times \frac{4}{50}$; in 3 min., $\frac{6}{50} \times \frac{6}{50}$; in 6 min., $\frac{13}{50} \times \frac{13}{50}$; in 9 min., $\frac{9}{50} \times \frac{8}{50}$; and in 21 min., $\frac{16}{50} \times \frac{16}{50}$.	*After atropia*, the rate per 10 sec. was in 2 min., 44; in 7 min., 59; in 11 min., 37; and in 20 min., 32.	*After atropia*, the respirations soon became normal in character; and their rate was in 5 min., 13; in 6 min., 10; and in 11 min. 30 sec., 4. Afterwards, they consisted of infrequent and irregularly occurring gasps. The moist sounds ceased almost immediately, but they recurred at 9 min.	*After atropia*, there was neither defæcation nor urination.	*After atropia*, the fibrillary twitches remained very slightly marked until death. The state of general flaccidity was not improved. A few struggling irregular movements occurred now and again.
279.	3 lbs.	0·18	0·5	0·5	17	Death, in 40 min. after the administration of physostigma.	*With physostigma*, in 11 min., contraction from $\frac{13}{50} \times \frac{13}{50}$ to $\frac{6}{50} \times \frac{5}{50}$.	*With physostigma*, in 16 min., slowing from 43 to 8 per 10 sec.	*With physostigma*, in 16 min., about 1 feeble gasp per 10 sec. The original rate was 29 per 10 sec.	*With physostigma*, in 10 min., saliva was escaping from the mouth.	*With physostigma*, in 9 min., well-marked and general fibrillary twitches; and in 15 min., only rare and slight twitches. In 6 min., extension of the limbs; in 9 min., decided paralysis; and in 14 min., general flaccidity, the animal lying on the side.
							After atropia, the size was in 3 min., $\frac{5}{50} \times \frac{4}{50}$; in 7 min., $\frac{8}{50} \times \frac{7}{50}$; and in 20 min., $\frac{10}{50} \times \frac{10}{50}$.—After death, it was in 5 min., $\frac{8}{50} \times \frac{7}{50}$.	*After atropia*, the rate per 10 sec. was in 1 min., 25; in 3 min., 54; in 6 min., 59; in 10 min., 60; in 18 min., 30; and in 20 min. 30 sec., 20.	*After atropia*, in 2 min., the respirations were nearly normal, and at the rate of 12 per 10 sec. The rate per 10 sec. was in 5 min., 8; and in 10 min., 5. Afterwards, only infrequent and feeble gasps occurred irregularly until death. The moist sounds were present uninterruptedly until death.	*After atropia*, the salivation was not checked. There was neither defæcation nor urination.	*After atropia*, the fibrillary twitches became again well marked; but after 13 min., they were only slight. The state of general flaccidity was not improved. Occasionally, some feeble tremors occurred.

TABLE 3.—EXPERIMENTS IN WHICH ATROPIA WAS ADMINISTERED BEFORE PHYSOSTIGMA.

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Interval of Time (in minutes).	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c
280.	3 lbs.	0·01	0·01	0·18	5	Death, in 20 min. after the administration of physostigma.	*With atropia*, in 4 min., dilatation from $\frac{13}{50} \times \frac{12}{50}$ to $\frac{14}{50} \times \frac{14}{50}$. *After physostigma*, the size was in 6 min., $\frac{16}{50} \times \frac{16}{50}$; in 8 min., $\frac{10}{50} \times \frac{10}{50}$; in 16 min., $\frac{7}{50} \times \frac{6}{50}$; and in 19 min., $\frac{7}{50} \times \frac{6}{50}$.—After death, it was in 2 min., $\frac{4}{50} \times \frac{3}{50}$; in 26 min., $\frac{9}{50} \times \frac{8}{50}$; and in 1 hour, $\frac{10}{50} \times \frac{10}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 45 to 49 per 10 sec. *After physostigma*, the rate per 10 sec. was in 3 min., 50; in 13 min., 30; in 18 min., 20; and in 19 min., 8.	*With atropia*, none. The original rate was 19 per 10 sec. *After physostigma*, the rate per 10 sec. was in 7 min., 18; and in 15 min., 12. After 18 min., only laboured, gasping movements occurred.	*With atropia*, none. *After physostigma*, in 16 min., saliva was freely escaping, and there was considerable accumulation of fluid in the fauces. There was neither defæcation nor urination.	*With atropia*, none. *After physostigma*, in 1 min. 30 sec., slight and infrequent fibrillary twitches, which were pretty well marked in 16 min., and continued for about 14 min. after death. In 6 min., extension of the limbs; in 10 min., decided paralysis; and in 18 min., general flaccidity. Occasionally, feeble tremors occurred.—There was no appearance of rigor at 1 hour 5 min. after death (temp. of laboratory, 58° F.).
281. *a* [Experiment *b* was performed thirteen days after experiment *a*.]	3 lbs.	0·02	0·02	0·18	5	Recovery.	*With atropia*, in 4 min., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{16}{50} \times \frac{15}{50}$. *After physostigma*, the size was in 1 min., $\frac{16}{50} \times \frac{16}{50}$; in 6 min., $\frac{17}{50} \times \frac{17}{50}$; and in 1 hour 35 min., $\frac{17}{50} \times \frac{17}{50}$.—On the following day, it was $\frac{15}{50} \times \frac{15}{50}$; and on the 14th day, $\frac{14}{50} \times \frac{13}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 40 to 47 per 10 sec. *After physostigma*, the rate per 10 sec. was in 2 min., 50; and in 7 min., 49. It could not afterwards be counted because of the fibrillary twitches.—On the following day, it was 28; and on the 14th day, 42.	*With atropia*, none. The original rate was 16 per 10 sec. *After physostigma*, the rate per 10 sec. was in 3 min., 16; in 36 min., 20; in 50 min., 20; and in 1 hour 36 min., 18. No moist sounds occurred.	*With atropia*, none. *After physostigma*, in 26 min., urine was freely voided. There was neither defæcation nor salivation during the 1 hour 48 min. of continuous observation.	*With atropia*, none. *After physostigma*, in 1 min. 30 sec., slight fibrillary twitches, which gradually increased until, in 14 min., they were very well marked. In 25 min., slight paralysis; in 38 min., very advanced paralysis; and in 1 hour 35 min., only slight paralysis. Frequently, there were tremors and starts.
	3 lbs.	0	0	0·12	—	Death, in 19 min.	—	—	—	—	—
282. *a* [Experiment *b* was performed sixteen days after experiment *a*.]	3 lbs.	0·05	0·05	0·18	5	Recovery.	*With atropia*, in 4 min. 30 sec., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{16}{50} \times \frac{14}{50}$. *After physostigma*, the size was in 14 min., $\frac{18}{50} \times \frac{18}{50}$; and in 1 hour 10 min., $\frac{16}{50} \times \frac{16}{50}$.—On the 3d day, it was $\frac{15}{50} \times \frac{14}{50}$; and on the 17th day, $\frac{13}{50} \times \frac{12}{50}$.	*With atropia*, in 4 min., acceleration from 40 to 46 per 10 sec. *After physostigma*, the rate per 10 sec. was in 4 min., 54; in 6 min., 54; in 50 min., 30; and in 1 hour 12 min., 29.—On the 3d day, it was 33; and on the 17th day, 39.	*With atropia*, in 3 min. 30 sec., slowing from 23 to 21 per 10 sec. *After physostigma*, the rate per 10 sec. was in 3 min., 22; in 27 min., 14; and in 1 hour 11 min., 20.—On the 3d day, it was 14; and on the 17th day, 23.	*With atropia*, none. *After physostigma*, in 23 min., salivation commenced, and continued, along with accumulation of fluid in the fauces, for more than 1 hour. In 50 min., and several times afterwards, wet facal pellets were passed. There was no urination during the 1 hour 20 min. of continuous observation.	*With atropia*, none. *After physostigma*, in 14 min., well-marked fibrillary twitches were present, and they continued for more than 1 hour. In 8 min., extension of the limbs; in 14 min., decided paralysis; and in 50 min., very advanced paralysis, which had diminished only a little at 1 hour 20 min. Tremors occurred frequently.
	b 2 lbs. 15 oz.	0	0	0·12 (= nearly p. 3 lbs.)	—	Death, in 21 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Interval of Time (in minutes).	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
283. *a* [Experiment *b* was performed fifteen days after experiment *a*.]	3 lbs.	3·5	3·5	0·18	5	Recovery.	*With atropia*, in 4 min. 30 sec., dilatation from $\frac{13}{50} \times \frac{12}{50}$ to $\frac{18}{50} \times \frac{18}{50}$. *After physostigma*, the size was in 7 min., $\frac{17}{50} \times \frac{17}{50}$; in 22 min., $\frac{16}{50} \times \frac{16}{50}$; and in 3 hours 30 min., $\frac{16}{50} \times \frac{16}{50}$.—On the following day, it was $\frac{17}{50} \times \frac{17}{50}$; on the 3d day, $\frac{18}{50} \times \frac{18}{50}$; and on the 6th day, $\frac{12}{50} \times \frac{11}{50}$.	*With atropia*, in 4 min., acceleration from 37 to 58 per 10 sec. *After physostigma*, the rate per 10 sec. was in 9 min., 57; in 1 hour, 56; and in 3 hours 28 min., 57.—On the following day, it was 45; on the 3d day, 52; and on the 6th day, 40.	*With atropia*, in 3 min. 30 sec., acceleration from 26 to 32 per 10 sec. *After physostigma*, the rate per 10 sec. was in 8 min., 28; in 32 min., 19; in 1 hour 39 min., 10; in 2 hours, 15; and in 3 hours 30 min., 17.—On the following day, it was 6; and on the 3d day, 20.	*With atropia*, none. *After physostigma*, in 5 min., several normal fæcal pellets were passed. There was neither urination nor salivation during the 3 hours 30 min. of continuous observation.	*With atropia*, none. *After physostigma*, in 4 min., slight fibrillary twitches, which altogether ceased in 20 min. In 20 min., slight paralysis; and in 1 hour, very advanced paralysis, which had diminished but little in 3 hours. There were neither tremors nor spasms.
b	3 lbs. 1 oz.	0	0	0·12	—	Death, in 26 min.	—	—	—	—	—
284. *a* [Experiment *b* was performed twenty-one days after experiment *a*.]	3 lbs.	3·7	3·7	0·18	5	Recovery.	*With atropia*, in 3 min., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{17}{50} \times \frac{17}{50}$. *After physostigma*, the size was in 5 min., $\frac{17}{50} \times \frac{17}{50}$; in 1 hour, $\frac{17}{50} \times \frac{17}{50}$; and in 1 hour 40 min., $\frac{17}{50} \times \frac{17}{50}$.—On the following day, it was $\frac{17}{50} \times \frac{17}{50}$; and on the 22d day, $\frac{13}{50} \times \frac{13}{50}$.	*With atropia*, in 4 min., acceleration from 43 to 59 per 10 sec. *After physostigma*, the rate per 10 sec. was in 3 min., 60; in 1 hour, 52; and in 1 hour 45 min., 54.—On the following day, it was 25; and on the 22d day, 43.	*With atropia*, in 3 min., slowing from 21 to 18 per 10 sec. *After physostigma*, the rate per 10 sec. was in 8 min., 18; and in 1 hour 40 min., 15.—On the following day, it was 11.	*With atropia*, none. *After physostigma*, none. There was no defæcation, urination, nor salivation during the 1 hour 45 min. of continuous observation.	*With atropia*, none. *After physostigma*, in 2 min., slight fibrillary twitches, which became pretty well marked, and continued so for more than 1 hour. In 20 min., slight paralysis; and in 40 min., very advanced paralysis, which continued unchanged for more than 1 hour. Frequently, there were feeble tremors.
b	3 lbs. 3 oz.	0	0	0·13 (= 0·12 gr. p. 3 lbs.)	—	Death, in 35 min.	—	—	—	—	—
285.	3 lbs. 12 oz.	4·87	3·9	0·225	5	Death, in 44 min. after the administration of physostigma.	*With atropia*, in 3 min. 30 sec., dilatation from $\frac{16}{50} \times \frac{14}{50}$ to $\frac{17}{50} \times \frac{17}{50}$. *After physostigma*, the size was in 5 min., $\frac{17}{50} \times \frac{17}{50}$; and in 43 min., $\frac{18}{50} \times \frac{18}{50}$.—After death, it was in 6 min., $\frac{15}{50} \times \frac{15}{50}$; and in 16 min., $\frac{11}{50} \times \frac{11}{50}$.	*With atropia*, in 4 min., acceleration from 35 to 60 per 10 sec. *After physostigma*, the rate per 10 sec. was in 4 min., 54; in 10 min., 53; and in 34 min., 59.	*With atropia*, in 3 min., acceleration from 34 to 45 per 10 sec. *After physostigma*, the rate per 10 sec. was in 18 min., 40; in 32 min., 7; in 36 min., 5; and in 38 min., 4. Afterwards, only feeble gasps occurred.	*With atropia*, none. *After physostigma*, none. There was no salivation, defæcation, nor urination.	*With atropia*, none. *After physostigma*, in 3 min., slight fibrillary twitches, which soon became pretty well marked, but had altogether ceased at 32 min. In 15 min., slight paralysis; and in 34 min., general flaccidity. Occasionally, feeble tremors occurred.—There was no appearance of rigor at 16 min. after death (temp. of laboratory, 57° F.).

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Interval of Time (in minutes).	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
286.	2 lbs. 8 oz.	4·6	4	0·21	5	Death, in 46 min. after the administration of physostigma.	*With atropia*, in 2 min., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{16}{50} \times \frac{16}{50}$. *After physostigma*, the size was in 6 min., $\frac{16}{50} \times \frac{16}{50}$; in 35 min., $\frac{17}{50} \times \frac{17}{50}$; and in 44 min., $\frac{17}{50} \times \frac{17}{50}$.—After death, it was in 2 min., $\frac{13}{50} \times \frac{13}{50}$; in 7 min., $\frac{6}{50} \times \frac{5}{50}$; in 26 min., $\frac{9}{50} \times \frac{8}{50}$; and in 1 hour 25 min., $\frac{11}{50} \times \frac{10}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 41 to 58 per 10 sec. *After physostigma*, the rate per 10 sec. was in 3 min., 59; in 15 min., 48; in 40 min., 48; in 42 min., 39; and in 44 min., 26.	*With atropia*, none. The original rate was 24 per 10 sec. *After physostigma*, the rate per 10 sec. was in 4 min., 19; in 25 min., 20; in 32 min., 16; in 35 min., 8; in 40 min., 5; and in 44 min., 2.	*With atropia*, none. *After physostigma*, none. There was no salivation, defæcation, nor urination.	*With atropia*, none. *After physostigma*, in 2 min., slight fibrillary twitches, which had altogether ceased at 25 min. In 25 min., slight paralysis; and in 34 min., general flaccidity. Frequently, feeble tremors occurred.—The first appearance of rigor was at 1 hour 24 min. after death (temp. of laboratory, 58° F.).
287.	3 lbs. 1 oz.	4·38	4·3	0·18	5	Death, in 42 min. after the administration of physostigma.	*With atropia*, in 3 min., dilatation from $\frac{12}{50} \times \frac{12}{50}$ to $\frac{16}{50} \times \frac{16}{50}$. *After physostigma*, the size was in 3 min., $\frac{17}{50} \times \frac{17}{50}$; in 36 min., $\frac{16}{50} \times \frac{16}{50}$; in 41 min., $\frac{10}{50} \times \frac{16}{50}$; and in 41 min. 30 sec., $\frac{19}{50} \times \frac{19}{50}$.—After death, it was in 30 sec., $\frac{18}{50} \times \frac{18}{50}$; in 2 min., $\frac{16}{50} \times \frac{16}{50}$; in 12 min., $\frac{10}{50} \times \frac{10}{50}$; and in 37 min., $\frac{12}{50} \times \frac{12}{50}$.	*With atropia*, in 3 min. 30 sec., acceleration from 40 to 61 per 10 sec. *After physostigma*, the rate per 10 sec. was in 3 min., 60; in 5 min., 50; in 8 min., 48; in 12 min., 54; in 20 min., 60; in 35 min., 58; in 36 min., 50; and in 41 min., 51.	*With atropia*, none. The original rate was 22 per 10 sec. *After physostigma*, the rate per 10 sec. was in 4 min., 26; in 15 min., 23; in 26 min., 19; and in 34 min., 12. Afterwards, only feeble gasps occurred very irregularly.	*With atropia*, none. *After physostigma*, none. There was no salivation, defæcation, nor urination.	*With atropia*, none. *After physostigma*, in 1 min. 30 sec., slight fibrillary twitches, which soon became pretty well marked, but ceased shortly before death. In 15 min., slight paralysis; and in 35 min., general flaccidity. Frequently, tremors and weak spasms occurred.—There was no appearance of rigor at 37 min. after death (temp. of laboratory, 58° F.).
288.	3 lbs. 9 oz.	5·3	4·5	0·25	5	Death, in 39 min. after the administration of physostigma.	*With atropia*, in 3 min., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{17}{50} \times \frac{17}{50}$. *After physostigma*, the size was in 2 min., $\frac{18}{50} \times \frac{18}{50}$; in 21 min., $\frac{18}{50} \times \frac{18}{50}$; and in 38 min., $\frac{18}{50} \times \frac{18}{50}$.—After death, it was in 1 min., $\frac{14}{50} \times \frac{14}{50}$; in 2 min., $\frac{11}{50} \times \frac{11}{50}$; in 25 min., $\frac{9}{50} \times \frac{8}{50}$; and in 45 min., $\frac{9}{50} \times \frac{8}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 44 to 62 per 10 sec. *After physostigma*, the rate per 10 sec. was in 4 min., 60; in 9 min., 61; in 32 min., 62; and in 37 min., 36.	*With atropia*, in 4 min., acceleration from 20 to 24 per 10 sec. *After physostigma*, the rate per 10 sec. was in 2 min., 26; in 15 min., 24; in 25 min., 16; in 29 min., 10; and in 30 min., 2. Afterwards, only gasping movements occurred at irregular intervals.	*With atropia*, none. *After physostigma*, none. There was no salivation, defæcation, nor urination.	*With atropia*, none. *After physostigma*, in 5 min., slight fibrillary twitches, which disappeared before death, without becoming more prominent. In 19 min., slight paralysis; and in 25 min., general flaccidity. Tremors occurred frequently, and on one or two occasions there were some feeble spasms.—Rigor first began to set in at about 45 min. after death (temp. of laboratory, 57° F.).

Number of Experiment.	Weight of Rabbit.	phate of Atropia (in Grains). Actual Dose.	phate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	sostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Interval of Time (in minutes).	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
289.	3 lbs.	5	5	0·18	5	Death, in 31 min. after the administration of physostigma.	*With atropia*, in 4 min., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{18}{50} \times \frac{18}{50}$. *After physostigma*, the size was in 6 min., $\frac{19}{50} \times \frac{19}{50}$; in 24 min., $\frac{20}{50} \times \frac{20}{50}$; and in 35 min. 30 sec., $\frac{20}{50} \times \frac{20}{50}$. —After death, it was in 1 min., $\frac{20}{50} \times \frac{20}{50}$; in 3 min., $\frac{15}{50} \times \frac{15}{50}$; in 27 min., $\frac{13}{50} \times \frac{13}{50}$; and in 2 hours, $\frac{10}{50} \times \frac{10}{50}$.	*With atropia*, none noted. The original rate was 41 per 10 sec. *After physostigma*, the rate per 10 sec. was in 25 min., 60; in 29 min., 32; and in 30 min. 30 sec., 20 (feeble).	*With atropia*, in 4 min. 30 sec., slowing from 22 to 18 per 10 sec. *After physostigma*, the rate per 10 sec. was in 6 min., 18; and in 23 min., 14. Afterwards, only feeble gasps occurred irregularly and infrequently.	*With atropia*, none. *After physostigma*, none. There was no salivation, defæcation, nor urination.	*With atropia*, none. *After physostigma*, in 4 min., slight fibrillary twitches, which soon became pretty well marked, but ceased before death. In 12 min., slight paralysis; and in 23 min., general flaccidity. Tremors occurred frequently.—There was no appearance of rigor at 2 hours after death (temp. of laboratory, 59° F.).
290. *a* [Experiment *b* was performed six days after experiment *a*.]	3 lbs.	0·05	0·05	0·18	10	Recovery.	*With atropia*, in 9 min., dilatation from $\frac{10}{50} \times \frac{9}{50}$ to $\frac{17}{50} \times \frac{18}{50}$. *After physostigma*, the size was in 20 min., $\frac{17}{50} \times \frac{18}{50}$; in 51 min., $\frac{18}{50} \times \frac{18}{50}$; and in 2 hours 43 min., $\frac{16}{50} \times \frac{16}{50}$.—On the following day, it was $\frac{11}{50} \times \frac{10}{50}$; and on the 7th day, $\frac{10}{50} \times \frac{10}{50}$.	*With atropia*, in 9 min. 30 sec., acceleration from 43 to 59 per 10 sec. *After physostigma*, the rate per 10 sec. was in 4 min., 64; in 47 min., 58; and in 1 hour 40 min., 58.—On the following day, it was 30; on the 3d day, 43; and on the 7th day, 40.	*With atropia*, in 7 min., acceleration from 24 to 27 per 10 sec. *After physostigma*, the rate per 10 sec. was in 2 min., 30; in 51 min., 21; in 1 hour 55 min., 22; and in 2 hours 47 min., 21.—On the following day, it was 19; and on the 7th day, 18.	*With atropia*, none. *After physostigma*, none. There was no salivation, defæcation, nor urination during the 3 hours of continuous observation.	*With atropia*, none. *After physostigma*, in 1 min. 30 sec., rare and slight fibrillary twitches, which soon became very well marked and continued so for more than 2 hours 30 min. In 5 min., slight paralysis; in 20 min., very decided paralysis; and in 2 hours 50 min., almost no paralysis. Occasionally, tremors and starts occurred.
	3 lbs. 1 oz.	0	0	0·18	—	Death, in 14 min.	—	—	—	—	—
291. *a* [Experiment *b* was performed six days after experiment *a*.]	3 lbs.	0·05	0·05	0·18	15	Recovery.	*With atropia*, in 8 min., dilatation from $\frac{11}{50} \times \frac{10}{50}$ to $\frac{16}{50} \times \frac{16}{50}$. *After physostigma*, the size was in 7 min., $\frac{16}{50} \times \frac{16}{50}$; in 33 min., $\frac{16}{50} \times \frac{16}{50}$; in 1 hour 17 min., $\frac{14}{50} \times \frac{14}{50}$; and in 2 hours 10 min., $\frac{13}{50} \times \frac{13}{50}$.—On the following day, it was $\frac{15}{50} \times \frac{14}{50}$; and on 6th day, $\frac{13}{50} \times \frac{12}{50}$.	*With atropia*, in 13 min., acceleration from 41 to 60 per 10 sec. *After physostigma*, the rate per 10 sec. was in 3 min., 61; in 5 min., 52; in 46 min., 44; and in 2 hours 11 min., 39.—On the following day, it was 26; and on the 5th day, 41.	*With atropia*, in 12 min., slowing from 19 to 17 per 10 sec. *After physostigma*, the rate per 10 sec. was in 2 min., 24; in 9 min., 29; in 1 hour 18 min., 20; and in 2 hours 10 min., 21.—On the following day, it was 22; and on the 6th day, 18.	*With atropia*, none. *After physostigma*, none. There was no salivation, defæcation, nor urination during the 4 hours of continuous observation.	*With atropia*, none. *After physostigma*, in 1 min. 30 sec., slight and rare fibrillary twitches, which soon became very well marked, and continued so for more than 3 hours. In 12 min., slight paralysis; in 45 min., very decided paralysis; and in 4 hours, only slight paralysis.
	3 lbs.	0	0	0·12	—	Death, in 23 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Interval of Time (in minutes).	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
292. *a* [Experiment *b* was performed seven days after experiment *a*.]	3 lbs. 1 oz.	0·05	0·05	0·18	20	Recovery.	*With atropia*, in 12 min., dilatation from $\frac{13}{50} \times \frac{13}{50}$ to $\frac{16}{50} \times \frac{17}{50}$. *After physostigma*, the size was in 5 min., $\frac{16}{50} \times \frac{17}{50}$; in 2 hours, $\frac{16}{50} \times \frac{17}{50}$; and in 3 hours, $\frac{16}{50} \times \frac{17}{50}$.—On the 3d day, it was $\frac{13}{50} \times \frac{12}{50}$; and on the 8th day, $\frac{12}{50} \times \frac{11}{50}$.	*With atropia*, in 16 min., acceleration from 44 to 61 per 10 sec. *After physostigma*, the rate per 10 sec. was in 4 min., 61; in 11 min., 53; in 40 min., 46; in 1 hour 21 min., 42; and in 3 hours 5 min., 43.—On the following day, it was 35; on the 3d day, 44; and on the 8th day, 42.	*With atropia*, in 12 min, slowing from 27 to 23 per 10 sec.; and in 19 min., acceleration to 29. *After physostigma*, the rate per 10 sec. was in 3 min., 30; in 40 min., 25; in 1 hour 20 min., 19; and in 3 hours 4 min., 23.—On the following day, it was 20; and on the 8th day, 17.	*With atropia*, none. *After physostigma*, in 1 hour 14 min., urine was voided. There was neither salivation nor defæcation during the 3 hours 30 min. of continuous observation.	*With atropia*, none. *After physostigma*, in 1 min. 30 sec., rare and slight fibrillary twitches, which became very well marked, and continued for more than 3 hours, though latterly in a less prominent form. In 13 min., slight paralysis; in 1 hour 10 min., very advanced paralysis; and in 3 hours, distinct, though comparatively slight, paralysis. Frequently, there were tremors and feeble spasms.
	b 2 lbs. 15½ oz.	0	0	0·17 (= about 0·18 gr. p. 3 lbs.)	—	Death, in 15 min.	—	—	—	—	—
293.	3 lbs. 10 oz.	0·06	0·05	0·217	25	Death, in 49 min. after the administration of physostigma.	*With atropia*, in 19 min., dilatation from $\frac{11}{50} \times \frac{11}{50}$ to $\frac{17}{50} \times \frac{17}{50}$. *After physostigma*, the size was in 10 min., $\frac{17}{50} \times \frac{17}{50}$; in 25 min., $\frac{17}{50} \times \frac{17}{50}$; in 30 min., $\frac{9}{50} \times \frac{9}{50}$; in 34 min., $\frac{8}{50} \times \frac{7}{50}$; in 38 min., $\frac{12}{50} \times \frac{12}{50}$; in 40 min., $\frac{7}{50} \times \frac{6}{50}$; in 46 min., $\frac{12}{50} \times \frac{12}{50}$; and in 49 min., $\frac{13}{50} \times \frac{13}{50}$.—After death, it was in 3 min., $\frac{12}{50} \times \frac{12}{50}$; in 11 min., $\frac{7}{50} \times \frac{7}{50}$; in 14 min., $\frac{10}{50} \times \frac{10}{50}$; and in 1 hour, $\frac{14}{50} \times \frac{14}{50}$.	*With atropia*, in 23 min., acceleration from 42 to 59 per 10 sec. *After physostigma*, the rate per 10 sec. was in 5 min., 46; in 15 min., 43; in 26 min., 23; and in 42 min., 12.	*With atropia*, in 24 min., slowing from 21 to 19 per 10 sec. *After physostigma*, the rate per 10 sec. was in 3 min., 21; in 16 min., 26; in 27 min., 18; and in 34 min., 10. Afterwards, only infrequent laboured gasps occurred.	*With atropia*, none. *After physostigma*, in 36 min., several normal fæcal pellets were passed; and in 34 min., salivation commenced, and it continued until death.	*With atropia*, none. *After physostigma*, in 2 min., slight fibrillary twitches, which by-and-by became very well marked, but were again only slight for several minutes before death. In 9 min., extension of the limbs; in 11 min., distinct paralysis; and in 31 min., general flaccidity. There were frequent tremors.—Rigor began to set in at 42 min. after death (temp. of laboratory, 60° F.).
294.	3 lbs. 2 oz.	0·052	0·05	0·19	30	Death, in 19 min. after the administration of physostigma.	*With atropia*, in 21 min., dilatation from $\frac{15}{50} \times \frac{14}{50}$ to $\frac{18}{50} \times \frac{18}{50}$. *After physostigma*, the size was in 9 min., $\frac{18}{50} \times \frac{18}{50}$; in 16 min., $\frac{10}{50} \times \frac{10}{50}$; in 17 min., $\frac{7}{50} \times \frac{6}{50}$; and in 18 min. 30 sec., $\frac{10}{50} \times \frac{9}{50}$.—After death, it was in 1 min., $\frac{9}{50} \times \frac{8}{50}$; in 4 min., $\frac{7}{50} \times \frac{6}{50}$; in 1 hour, $\frac{11}{50} \times \frac{10}{50}$; and in 1 hour	*With atropia*, in 8 min., acceleration from 40 to 60 per 10 sec., this rate being also present at 29 min. *After physostigma*, the rate per 10 sec. was in 5 min., 43; in 7 min., 32; and in 16 min. 30 sec., 16.	*With atropia*, none. The original rate was 22 per 10 sec. *After physostigma*, the rate per 10 sec. was in 6 min., 24; in 7 min., 17; and in 9 min., 16. Soon afterwards, the respirations became irregular, infrequent, and gasping, and also accompanied with moist sounds.	*With atropia*, in 17 min., urine was voided; and in 27 min., several normal fæcal pellets were passed. *After physostigma*, in 7 min., slight increase in the secretion of certain buccal glands, and by-and-by a little salivation. In 10 min. and in 15 min., several fæcal pellets were passed. There was no urination.	*With atropia*, none. *After physostigma*, in 2 min., slight fibrillary twitches, which soon became pretty well marked. In 10 min., extension of the limbs; in 12 min., decided paralysis; and in 16 min., general flaccidity. Occasionally, there were some feeble tremors.—Ri-

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Interval of Time (in minutes).	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
295. [Experiment *b* was performed seven days after experiment *a*.]											
a	3 lbs.	0·5	0·5	0·18	15	Recovery.	*With atropia*, in 14 min., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{15}{50} \times \frac{15}{50}$. *After physostigma*, the size was in 10 min., $\frac{15}{50} \times \frac{15}{50}$; and in 3 hours, $\frac{15}{50} \times \frac{15}{50}$.—On the following day, it was $\frac{15}{50} \times \frac{15}{50}$; on the 4th day, $\frac{14}{50} \times \frac{13}{50}$; and on the 8th day, $\frac{11}{50} \times \frac{10}{50}$.	*With atropia*, in 14 min. 30 sec., acceleration from 41 to 60 per 10 sec. *After physostigma*, the rate per 10 sec. was in 5 min., 60; and in 1 hour 46 min., 38.—On the following day, it was 28; on the 3d day, 30; on the 4th day, 40; and on the 8th day, 41.	*With atropia*, in 13 min., acceleration from 37 to 41 per 10 sec. *After physostigma*, the rate per 10 sec. was in 3 min., 42; in 26 min., 40; in 48 min., 26; and in 1 hour 47 min., 28.—On the following day, it was 23; and on the 8th day, 21.	*With atropia*, none. *After physostigma*, in 46 min., slight increase in the secretion of certain buccal glands. In 51 min., in 1 hour 8 min., and in 1 hour 45 min., several fæcal pellets were passed; and in 1 hour 8 min., a little urine was voided.	*With atropia*, in 12 min., slight restlessness. *After physostigma*, in 2 min., slight fibrillary twitches, which became very well marked, and continued so for more than 3 hours. In 14 min., slight paralysis; in 46 min., pretty advanced paralysis; and in 2 hours 30 min., only slight paralysis. Frequently, tremors occurred.
b	2 lbs. 15 oz.	0	0	0·12 (= about 0·12 gr. p. 3 lbs.)	—	Death, in 23 min.	—	—	—	—	—
296. [Experiment *b* was performed six days after experiment *a*.]											
a	3 lbs. 11 oz.	0·61	0·5	0·22	25	Recovery.	*With atropia*, in 23 min., dilatation from $\frac{10}{50} \times \frac{9}{50}$ to $\frac{16}{50} \times \frac{16}{50}$. *After physostigma*, the size was in 20 min., $\frac{16}{50} \times \frac{16}{50}$; in 36 min., (R.P.) $\frac{15}{50} \times \frac{15}{50}$, (L.P.) $\frac{11}{50} \times \frac{10}{50}$; in 46 min. (both), $\frac{11}{50} \times \frac{10}{50}$; and in 1 hour 40 min., $\frac{11}{50} \times \frac{10}{50}$.—On the following day, it was $\frac{16}{50} \times \frac{16}{50}$; on the 3d day, $\frac{13}{50} \times \frac{12}{50}$; on the 4th day, $\frac{11}{50} \times \frac{10}{50}$; and on the 7th day, $\frac{10}{50} \times \frac{9}{50}$.	*With atropia*, in 18 min., acceleration from 39 to 60 per 10 sec. *After physostigma*, the rate per 10 sec. was in 7 min., 52; in 17 min., 46; in 40 min., 50; and in 1 hour 15 min., 42.—On the following day, it was 30; on the 3d day, 40; and on the 7th day, 43.	*With atropia*, none. The original rate was 32 per 10 sec. *After physostigma*, the rate per 10 sec. was in 9 min., 37; in 48 min., 28; and in 1 hour 20 min., 19.—On the following day, it was 25; and on the 7th day, 27.	*With atropia*, in 18 min., several fæcal pellets were passed. *After physostigma*, in 17 min., and in 30 min., several fæcal pellets were passed; and in 30 min., urine was voided. There was no salivation.	*With atropia*, in 16 min., slight restlessness. *After physostigma*, in 5 min., rare and slight fibrillary twitches, which by-and-by became well marked, and continued so for more than 1 hour. In 17 min., slight paralysis; in 35 min., decided paralysis; and in 1 hour 40 min., only slight paralysis. Occasionally, some spasmodic movements occurred.
b	3 lbs. 10 oz.	0	0	0·145 (= 0·12 gr. p. 3 lbs.)	—	Death, in 17 min.	—	—	—	—	—
297. [Experiment *b* was performed nine days after experiment *a*.]											
a	3 lbs.	0·5	0·5	0·18	30	Recovery.	*With atropia*, in 10 min., dilatation from $\frac{14}{50} \times \frac{14}{50}$ to $\frac{17}{50} \times \frac{17}{50}$. *After physostigma*, the size was in 7 min., $\frac{17}{50} \times \frac{17}{50}$; and in 2 hours, $\frac{17}{50} \times \frac{17}{50}$.—On the following day, it was $\frac{17}{50} \times \frac{17}{50}$; on the 3d day, $\frac{18}{50} \times \frac{18}{50}$; and on the 10th day, $\frac{16}{50} \times \frac{16}{50}$.	*With atropia*, in 9 min., acceleration from 43 to 62 per 10 sec., and in 25 min., to 65. *After physostigma*, the rate per 10 sec. was in 6 min., 57; in 9 min., 43; in 31 min., 48; and in 2 hours, 48.—On the following day, it was 30; on the 3d day, 39; and on the 10th day, 38.	*With atropia*, in 27 min., acceleration from 22 to 26 per 10 sec. *After physostigma*, the rate per 10 sec. was in 7 min., 17; in 29 min., 16; and in 2 hours 2 min., 19.—On the following day, it was 17; and on the 10th day, 13.	*With atropia*, none. *After physostigma*, in 6 min., several fæcal pellets were passed. Neither salivation nor urination occurred during the 2 hours 40 min. of continuous observation.	*With atropia*, in 10 min., slight restlessness. *After physostigma*, in 2 min., infrequent fibrillary twitches, which became pretty well marked, and continued so for more than 1 hour 50 min. In 17 min., slight paralysis; in 28 min., distinct, but not very advanced paralysis; and in 1 hour 40 min., only slight paralysis. Occasionally, there were some gentle tremors.
b	2 lbs. 15 oz.	0	0	0·175 (= 0·18 gr. p. 3 lbs.)	—	Death in 11 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Interval of Time (in minutes).	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
298.	3 lbs. 8 oz.	0·58	0·5	0·21	35	Death, in 1 hour 17 min. after the administration of physostigma.	*With atropia*, in 10 min., dilatation from $\frac{15}{50}\times\frac{14}{50}$ to $\frac{18}{50}\times\frac{18}{50}$, the latter being the size also at 34 min. *After physostigma*, the size was in 5 min., $\frac{19}{50}\times\frac{19}{50}$; in 40 min., $\frac{19}{50}\times\frac{19}{50}$; in 1 hour, $\frac{15}{50}\times\frac{15}{50}$; in 1 hour 8 min., $\frac{8}{50}\times\frac{7}{50}$; in 1 hour 15 min., $\frac{7}{50}\times\frac{6}{50}$; and in 1 hour 17 min., $\frac{10}{50}\times\frac{10}{50}$.—After death, it was in 2 min., $\frac{10}{50}\times\frac{10}{50}$; in 12 min., $\frac{9}{50}\times\frac{9}{50}$; and in 42 min., $\frac{11}{50}\times\frac{11}{50}$.	*With atropia*, in 20 min., acceleration from 40 to 60 per 10 sec., the latter being the rate also at 34 min. *After physostigma*, the rate per 10 sec. was in 5 min., 60; in 1 hour, 42; and in 1 hour 12 min., 18.	*With atropia*, in 34 min. 30 sec., acceleration from 40 to 42 per 10 sec. *After physostigma*, the rate per 10 sec. was in 8 min., 45; in 15 min., 32; in 32 min., 30; in 40 min., 18; in 55 min., 16; and in 1 hour 9 min., 8. Afterwards, only laboured, noisy, and gasping respirations occurred.	*With atropia*, none. *After physostigma*, in 43 min., slight salivation, which soon became pretty abundant, and was accompanied with noisy respirations. In 1 hour 10 min., several fæcal pellets were passed, and urine was voided.	*With atropia*, in 33 min., slight restless movements of head. *After physostigma*, in 2 min., slight fibrillary twitches, which soon became pretty well marked, but afterwards lessened greatly. In 13 min., slight paralysis; and in 1 hour 10 min., general flaccidity. Tremors and starts occurred frequently.—There was no appearance of rigor at 43 min. after death (temp. of laboratory, 62° F.).
299.	3 lbs.	0·5	0·5	0·18	40	Death, in 1 hour 13 min. after the administration of physostigma.	*With atropia*, in 7 min., dilatation from $\frac{14}{50}\times\frac{13}{50}$ to $\frac{17}{50}\times\frac{17}{50}$. In 37 min., the size was also $\frac{17}{50}\times\frac{17}{50}$. *After physostigma*, the size was in 5 min., $\frac{17}{50}\times\frac{17}{50}$; in 10 min., $\frac{18}{50}\times\frac{18}{50}$; in 40 min., $\frac{18}{50}\times\frac{18}{50}$; in 52 min., $\frac{12}{50}\times\frac{12}{50}$; and in 1 hour 12 min., $\frac{11}{50}\times\frac{11}{50}$.—After death, it was in 3 min., $\frac{10}{50}\times\frac{10}{50}$; and in 38 min., $\frac{11}{50}\times\frac{11}{50}$.	*With atropia*, in 4 min., acceleration from 39 to 61 per 10 sec. In 38 min., the rate was 57 per 10 sec. *After physostigma*, the rate per 10 sec. was in 4 min., 49; in 24 min., 36; in 53 min., 25; and in 1 hour 10 min., 11.	*With atropia*, none. The original rate was 19 per 10 sec. *After physostigma*, the rate per 10 sec. was in 9 min., 22; in 25 min., 18; in 1 hour 5 min., 10; and in 1 hour 10 min., 6. Afterwards, only laboured and infrequent gasps occurred irregularly.	*With atropia*, in 23 min., several fæcal pellets were passed. *After physostigma*, in 15 min., and in 35 min., urine was freely voided. In 35 min., and in 50 min., fæcal pellets were passed, on the latter occasion, wet on the surface. In 58 min., salivation commenced; and afterwards, the respirations were often noisy.	*With atropia*, none. *After physostigma*, in 1 min. 20 sec., rare fibrillary twitches, which by-and-by became well marked. In 12 min., slight paralysis; in 28 min., decided paralysis; and in 1 hour 5 min., general flaccidity. Occasionally, there were some feeble tremors.—Rigor began to set in at 37 min. after death (temp. of laboratory, 58° F.).
300. [Experiment *b* was performed eleven days after experiment *a*.]	*a* 2 lbs. 15½ oz.	1·5	1·5	0·18	15	Recovery.	*With atropia*, in 2 min., dilatation from $\frac{10}{50}\times\frac{9}{50}$ to $\frac{15}{50}\times\frac{15}{50}$. *After physostigma*, the size was in 3 min., $\frac{15}{50}\times\frac{15}{50}$; in 50 min., $\frac{13}{50}\times\frac{12}{50}$; and in 1 hour 10 min., $\frac{12}{50}\times\frac{11}{50}$.—On the 3d day, it was $\frac{13}{50}\times\frac{13}{50}$; on the 4th day, $\frac{10}{50}\times\frac{10}{50}$; and on the 12th day, $\frac{10}{50}\times\frac{9}{50}$.	*With atropia*, in 4 min., acceleration from 39 to 59 per 10 sec. *After physostigma*, the rate per 10 sec. was in 5 min., 59; in 11 min., 61; in 30 min., 50; in 50 min., 45; and in 1 hour 5 min., 42.—On the 3d day, it was 32; on the 4th day, 28; and on the 12th day, 43.	*With atropia*, in 14 min., acceleration from 22 to 23 per 10 sec. *After physostigma*, the rate per 10 sec. was in 11 min., 25; in 20 min., 19; in 30 min., 16; and in 1 hour 6 min., 15.—On the 3d day, it was 21; on the 4th day, 20; and on 12th day, 24.	*With atropia*, none. *After physostigma*, in 9 min., in 1 hour 5 min., and in 2 hours 25 min., fæcal pellets were passed, on the last occasion, wet on the surface. In 46 min., urine was freely voided. There was no salivation.	*With atropia*, in 5 min., slight restlessness. *After physostigma*, in 2 min., rare fibrillary twitches, which became well marked, and continued for more than 2 hours. In 18 min., slight paralysis; in 45 min., decided paralysis; and in 1 hour 10 min., only slight paralysis. There were no tremors.
	b 3 lbs.	0	0	0·18	—	Death, in 18 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Interval of Time (in minutes).	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
301. [Experiment *b* was performed eight days after experiment *a*.]											
a	2 lbs. 15 oz.	1·46	1·5	0·176	30	Recovery.	*With atropia*, in 5 min., dilatation from $\frac{11}{50}\times\frac{10}{50}$ to $\frac{16}{50}\times\frac{16}{50}$, the latter being the size also at 28 min. *After physostigma*, the size was in 5 min., $\frac{16}{50}\times\frac{16}{50}$; in 40 min., $\frac{16}{50}\times\frac{16}{50}$; and in 1 hour, $\frac{16}{50}\times\frac{16}{50}$.—On the following day, it was $\frac{15}{50}\times\frac{15}{50}$; on the 6th day, $\frac{11}{50}\times\frac{10}{50}$; and on the 9th day, $\frac{11}{50}\times\frac{10}{50}$.	*With atropia*, in 6 min., acceleration from 41 to 61 per 10 sec. In 29 min., the rate per 10 sec. was 53. *After physostigma*, the rate per 10 sec. was in 4 min., 51; in 11 min., 46; in 20 min., 55; and in 1 hour 5 min., 40.—On the following day, it was 29; on the 3d day, 39; and on the 9th day, 42.	*With atropia*, none. The original rate was 23 per 10 sec. *After physostigma*, the rate per 10 sec. was in 3 min., 20; in 8 min., 19; in 25 min., 17; in 55 min., 15; and in 1 hour, 15.—On the following day, it was 15; on the 3d day, 21; on the 5th day, 15; and on the 9th day, 17.	*With atropia*, none. *After physostigma*, none. There was no defæcation, urination, nor salivation during the 1 hour 40 min. of continuous observation.	*With atropia*, slight restlessness. *After physostigma*, in 1 min. 30 sec., rare fibrillary twitches, which soon became very well marked, and continued for more than 1 hour. In 17 min., extension of the limbs; in 18 min., distinct paralysis; in 40 min., very decided paralysis; and in 1 hour, only slight paralysis. Occasionally, some tremors and starts occurred.
b	2 lbs. 15½ oz.	0	0	0·17 (= 0·18 gr. p. 3 lbs.)	—	Death, in 14 min.	—	—	—	—	—
302. [Experiment *b* was performed six days after experiment *a*.]											
a	3 lbs.	1·5	1·5	0·18	40	Recovery.	*With atropia*, in 4 min., dilatation from $\frac{12}{50}\times\frac{12}{50}$ to $\frac{16}{50}\times\frac{16}{50}$. In 39 min. the size was $\frac{15}{50}\times\frac{15}{50}$. *After physostigma*, the size was in 3 min., $\frac{15}{50}\times\frac{15}{50}$; in 30 min., $\frac{15}{50}\times\frac{16}{50}$; and in 1 hour 15 min., $\frac{15}{50}\times\frac{15}{50}$.—On the following day, it was $\frac{17}{50}\times\frac{17}{50}$; on the 4th day, $\frac{16}{50}\times\frac{15}{50}$; and on the 7th day, $\frac{15}{50}\times\frac{15}{50}$.	*With atropia*, in 3 min., acceleration from 41 to 55 per 10 sec. In 35 min., the rate per 10 sec. was 54. *After physostigma*, the rate per 10 sec. was in 15 min., 52; in 40 min., 45; in 1 hour 16 min., 40; and in 1 hour 35 min., 38.—On the following day, it was 33; on the 4th day, 42; and on the 7th day, 41.	*With atropia*, in 34 min., acceleration from 30 to 37 per 10 sec. *After physostigma*, the rate per 10 sec. was in 4 min., 38; in 27 min., 24; in 40 min., 18; and in 1 hour 35 min., 19.—On the following day, it was 30; and on the 7th day, 22.	*With atropia*, in 4 min., several fæcal pellets were passed. *After physostigma*, none. There was no defæcation, urination, nor salivation during the 1 hour 45 min. of continuous observation.	*With atropia*, after 11 min., there were constant restless movements. *After physostigma*, in 2 min., rare fibrillary twitches, which soon became well marked, and continued for more than 1 hour 40 min. In 12 min., slight paralysis; in 20 min., decided paralysis; and in 1 hour 45 min., only slight paralysis. Occasionally, tremors and starts occurred; and at 1 hour 40 min., there were some convulsive movements.
b	3 lbs.	0	0	0·18	—	Death, in 12 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Interval of Time (in minutes).	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
303. [Experiment *b* was performed eleven days after experiment *a*.]											
a	3 lbs. 3 oz.	1·59	1·5	0·19	60	Recovery.	*With atropia*, in 4 min., dilatation from $\frac{12}{50}\times\frac{12}{50}$ to $\frac{17}{50}\times\frac{17}{50}$. In 58 min., the size was $\frac{18}{50}\times\frac{18}{50}$. *After physostigma*, the size was in 30 min., $\frac{18}{50}\times\frac{18}{50}$; in 1 hour, $\frac{18}{50}\times\frac{18}{50}$; and in 2 hours, $\frac{18}{50}\times\frac{18}{50}$.—On the following day, it was $\frac{17}{50}\times\frac{17}{50}$; on the 5th day, $\frac{15}{50}\times\frac{15}{50}$; and on the 12th day, $\frac{12}{50}\times\frac{12}{50}$.	*With atropia*, in 57 min., acceleration from 42 to 60 per 10 sec. *After physostigma*, the rate per 10 sec. was in 4 min., 58; in 24 min., 42; in 1 hour 35 min., 27; and in 2 hours, 32.—On the following day, it was 31; on the 5th day, 37; and on the 12th day, 39.	*With atropia*, in 59 min., slowing from 33 to 23 per 10 sec. *After physostigma*, the rate per 10 sec. was in 3 min., 17; in 9 min., 44; in 21 min., 22; in 1 hour 17 min., 35; and in 2 hours 2 min., 32.—On the following day, it was 17; on the 5th day, 21; and on the 12th day, 18.	*With atropia*, in 55 min., several normal fæcal pellets were passed. *After physostigma*, in 25 min., salivation commenced, and soon became profuse. In 49 min., urine was freely voided; and in 1 hour 45 min., a large quantity of semi-liquid fæces were passed.	*With atropia*, after 18 min., slight restlessness was present. *After physostigma*, in 1 min. 30 sec., rare fibrillary twitches, which afterwards became very well marked, and continued for more than 1 hour 40 min. In 11 min., slight paralysis; in 19 min., very decided paralysis; and in 2 hours, slight, though still distinct, paralysis. Frequently, tremors occurred.
b	3 lbs. 4 oz.	0	0	0·19 (= 0·18 gr. p. 3 lbs.)	—	Death, in 19 min.	—	—	—	—	—
304. [Experiment *b* was performed eight days after experiment *a*.]											
a	3 lbs.	1·5	1·5	0·18	65	Recovery.	*With atropia*, in 4 min., dilatation from $\frac{14}{50}\times\frac{13}{50}$ to $\frac{18}{50}\times\frac{18}{50}$. In 62 min., the size was $\frac{16}{50}\times\frac{16}{50}$. *After physostigma*, the size was in 10 min., $\frac{16}{50}\times\frac{16}{50}$; in 30 min., $\frac{17}{50}\times\frac{17}{50}$; and in 2 hours 10 min., $\frac{17}{50}\times\frac{17}{50}$.—On the following day, it was $\frac{17}{50}\times\frac{17}{50}$; and on the 9th day, $\frac{14}{50}\times\frac{13}{50}$.	*With atropia*, in 6 min., acceleration from 42 to 61 per 10 sec. In 63 min., the rate per 10 sec. was 62. *After physostigma*, the rate per 10 sec. was in 5 min., 61; in 31 min., 43; in 50 min., 32; in 1 hour 43 min., 42; and in 2 hours 15 min., 42.—On the following day, it was 32; and on the 9th day, 40.	*With atropia*, in 10 min., slowing from 15 to 13 per 10 sec.; and in 62 min., to 10. *After physostigma*, the rate per 10 sec. was in 10 min., 16; in 40 min., 11; in 1 hour 40 min., 13; and in 2 hours 14 min., 12.—On the following day, it was 11; and on the 9th day, 15.	*With atropia*, none. *After physostigma*, none. There was no defæcation, urination, nor salivation during the 2 hours 20 min. of continuous observation.	*With atropia*, in 6 min., restlessness, which continued for about 40 min. *After physostigma*, in 1 min. 30 sec., rare fibrillary twitches, which by-and-by became well marked, and continued for more than 2 hours. In 18 min., distinct paralysis; in 40 min., very decided paralysis; and in 2 hours 20 min., distinct but greatly lessened paralysis.
b	3 lbs.	0	0	0·18	—	Death, in 12 min.	—	—	—	—	—
305.	2 lbs. 14 oz.	1·43	1·5	0·17	70	Death, in 1 hour after the administration of physostigma.	*With atropia*, in 7 min., dilatation from $\frac{14}{50}\times\frac{13}{50}$ to $\frac{17}{50}\times\frac{17}{50}$. In 65 min., the size was $\frac{17}{50}\times\frac{17}{50}$. *After physostigma*, the size was in 15 min., $\frac{16}{50}\times\frac{16}{50}$; in 35 min., $\frac{17}{50}\times\frac{17}{50}$; in 53 min., $\frac{18}{50}\times\frac{18}{50}$; and in 1 hour, $\frac{18}{50}\times\frac{18}{50}$.—After death, the size was in 2 min., $\frac{18}{50}\times\frac{18}{50}$; in 5 min., $\frac{16}{50}\times\frac{16}{50}$; in 25 min., $\frac{14}{50}\times\frac{14}{50}$; and in 37 min., $\frac{12}{50}\times\frac{12}{50}$.	*With atropia*, in 5 min., acceleration from 40 to 60 per 10 sec.; and in 66 min., to 62. *After physostigma*, the rate per 10 sec. was in 7 min., 48; in 50 min., 36; in 54 min., 24; and in 56 min., 14.	*With atropia*, none. The original rate was 23 per 10 sec. *After physostigma*, the rate per 10 sec. was in 10 min., 31; in 20 min., 22; in 41 min., 12; and in 45 min., 9. Afterwards, only infrequent gasps occurred irregularly until death.	*With atropia*, none. *After physostigma*, none.	*With atropia*, in 3 min., restlessness, which continued for about 28 min. *After physostigma*, in 2 min., rare fibrillary twitches, which became pretty well marked, but ceased before death. In 10 min., slight paralysis; in 19 min., decided paralysis; and in 46 min., general flaccidity. There were frequent tremors.—Rigor began to set in at 37 min. after death (temp. of laboratory, 61° F.).

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Interval of Time in (minutes).	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
306.	3 lbs.	1·5	1·5	0·18	80	Death, in 47 min. after the administration of physostigma.	*With atropia*, in 3 min., dilatation from $\frac{14}{50} \times \frac{13}{50}$; to $\frac{16}{50} \times \frac{16}{50}$; and in 5 min., to $\frac{17}{50} \times \frac{17}{50}$. *After physostigma*, the size was in 13 min., $\frac{17}{50} \times \frac{17}{50}$; in 30 min., $\frac{17}{50} \times \frac{17}{50}$; and in 47 min., $\frac{17}{50} \times \frac{17}{50}$.—After death, it was in 4 min., $\frac{12}{50} \times \frac{12}{50}$; in 6 min., $\frac{7}{50} \times \frac{6}{50}$; and in 52 min., $\frac{10}{50} \times \frac{10}{50}$.	*With atropia*, in 5 min., acceleration from 40 to 61 per 10 sec.; and in 70 min., to 63. *After physostigma*, the rate per 10 sec. was in 5 min., 54; in 17 min., 40; in 29 min., 30; in 38 min., 18; and in 40 min., 15.	*With atropia*, in 6 min., acceleration from 20 to 22 per 10 sec.; and in 79 min., slowing to 19. *After physostigma*, the rate per 10 sec. was in 15 min., 24; in 25 min., 12; in 34 min., 8; and in 43 min., 5. Afterwards, mere gasps occurred infrequently.	*With atropia*, in 12 min., and in 70 min., fæcal pellets were passed; and in 43 min., urine was freely voided. *After physostigma*, in 27 min., salivation commenced and continued until death. In 28 min., several fæcal pellets were passed. In 32 min., urine was voided.	*With atropia*, in 7 min., restlessness, which had ceased at 24 min. *After physostigma*, in 2 min., rare fibrillary twitches, which became well marked, and continued until several min. after death. In 13 min., slight paralysis; in 25 min., very decided paralysis; and in 40 min., general flaccidity. Occasionally, tremors occurred.—Rigor began to set in at about 53 min. after death (temp. of laboratory, 58° F.).
307. *a* [Experiment *b* was performed ten days after experiment *a*.]	3 lbs.	3	3	0·18	40	Recovery.	*With atropia*, in 37 min., dilatation from $\frac{15}{50} \times \frac{14}{50}$ to $\frac{18}{50} \times \frac{18}{50}$. *After physostigma*, the size was in 1 hour 10 min., $\frac{18}{50} \times \frac{18}{50}$.	*With atropia*, in 35 min., acceleration from 41 to 55 per 10 sec. *After physostigma*, the rate per 10 sec. was in 9 min., 48; and in 1 hour 6 min., 40.	*With atropia*, none. The original rate was 14 per 10 sec. *After physostigma*, the rate per 10 sec. was in 2 min., 15; in 10 min., 13; and in 1 hour 7 min., 12.	*With atropia*, none. *After physostigma*, none. There was no defæcation, urination, nor salivation during the 1 hour 15 min. of continuous observation.	*With atropia*, restlessness. *After physostigma*, in 3 min., slight fibrillary twitches, which afterwards increased somewhat, and then ceased. In 20 min., distinct paralysis; and in 1 hour 15 min., only slight paralysis. Occasionally, there were some feeble tremors.
b	3 lbs. 1 oz.	0	0	0·12	—	Death, in 30 min.	—	—	—	—	—
308. *a* [Experiment *b* was performed twelve days after experiment *a*].	3 lbs. 4 oz.	3·25	3	0·2	65	Recovery.	*With atropia*, in 3 min., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{17}{50} \times \frac{17}{50}$. In 50 min., the size was $\frac{16}{50} \times \frac{16}{50}$. *After physostigma*, the size was in 11 min., $\frac{16}{50} \times \frac{16}{50}$; and in 1 hour 20 min., $\frac{17}{50} \times \frac{17}{50}$.—On the following day, it was $\frac{17}{50} \times \frac{17}{50}$; on the 4th day, $\frac{16}{50} \times \frac{16}{50}$; and on the 13th day, $\frac{15}{50} \times \frac{15}{50}$.	*With atropia*, in 4 min., acceleration from 37 to 57 per 10 sec.; and in 52 min., to 60. *After physostigma*, the rate per 10 sec. was in 5 min., 55; in 35 min., 49; and in 1 hour 15 min., 51.—On the 3d day, it was 38; and on the 13th day, 43.	*With atropia*, in 50 min., slowing from 22 to 20 per 10 sec. *After physostigma*, the rate per 10 sec. was in 11 min., 18; in 40 min., 16; and in 1 hour 20 min., 14.—On the 3d day, it was 17; on the 4th day, 21; and on the 13th day, 14.	*With atropia*, none. *After physostigma*, none. There was no defæcation, urination, nor salivation during the 1 hour 30 min. of continuous observation.	*With atropia*, in 5 min., restless movements. *After physostigma*, in 3 min., slight fibrillary twitches, which ceased in 1 hour 5 min. In 17 min., slight paralysis; in 55 min., very decided paralysis; and in 1 hour 30 min., decided paralysis. Occasionally, there were some tremors and starts.
b	3 lbs. 5 oz.	0	0	0·135 (= 0·12 gr. p. 3 lbs.)	—	Death, in 26 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Interval of Time (in minutes.)	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
309. [Experiment *b* was performed ten days after experiment *a*.]											
a	3 lbs.	3	3	0·18	90	Recovery.	*With atropia*, in 2 min., dilatation from $\frac{15}{50}\times\frac{15}{50}$ to $\frac{16}{50}\times\frac{16}{50}$. In 89 min., the size was $\frac{15}{50}\times\frac{15}{50}$. *After physostigma*, the size was in 17 min., $\frac{16}{50}\times\frac{16}{50}$; and in 1 hour 15 min., $\frac{16}{50}\times\frac{16}{50}$.—On the following day, it was $\frac{18}{50}\times\frac{18}{50}$; on the 9th day, $\frac{17}{50}\times\frac{17}{50}$; and on the 11th day, $\frac{16}{50}\times\frac{15}{50}$.	*With atropia*, in 5 min., acceleration from 39 to 60 per 10 sec. In 88 min., the rate was 61 per 10 sec. *After physostigma*, the rate per 10 sec. was in 5 min., 60; in 13 min., 43; in 27 min., 41; and in 1 hour 20 min., 42.—On the following day, it was 37; and on the 9th day, 41.	*With atropia*, in 74 min., acceleration from 18 to 19 per 10 sec. *After physostigma*, the rate per 10 sec. was in 9 min., 13; in 25 min., 12; in 35 min., 12; and in 1 hour 16 min., 17.—On the following day, it was 12; and on the 9th day, 11.	*With atropia*, none. *After physostigma*, none. There was no defæcation, urination, nor salivation during the 1 hour 20 min. of continuous observation.	*With atropia*, in 4 min., restlessness, which had ceased by 65 min. *After physostigma*, in 3 min., slight fibrillary twitches, which had ceased, without increasing, by 35 min. In 13 min., slight paralysis; in 35 min., decided paralysis; and in 1 hour 20 min., distinct, though diminished, paralysis. Occasionally, some irregular, doubtfully spasmodic movements occurred.
b	3 lbs.	0	0	0·12	—	Death, in 18 min.	—	—	—	—	—
310. [Experiment *b* was performed thirteen days after experiment *a*.]											
a	3 lbs. 4 oz.	3·25	3	0·195	95	Recovery.	*With atropia*, in 85 min., dilatation from $\frac{10}{50}\times\frac{10}{50}$ to $\frac{17}{50}\times\frac{17}{50}$. *After physostigma*, the size was in 5 min., $\frac{17}{50}\times\frac{17}{50}$; in 40 min., $\frac{18}{50}\times\frac{18}{50}$; and in 1 hour 50 min., $\frac{17}{50}\times\frac{17}{50}$.—On the following day, it was $\frac{19}{50}\times\frac{19}{50}$; on the 6th day, $\frac{19}{50}\times\frac{19}{50}$; and on the 14th day, $\frac{17}{50}\times\frac{17}{50}$.	*With atropia*, in 5 min., acceleration from 41 to 60 per 10 sec. In 85 min., the rate was 58 per 10 sec. *After physostigma*, the rate per 10 sec. was in 4 min., 52; in 22 min., 42; and in 1 hour 50 min., 42.—On the following day, it was 37; on the 3d day, 42; and on the 14th day, 39.	*With atropia*, in 6 min., slowing from 37 to 21 per 10 sec., and in 86 min., to 16. *After physostigma*, the rate per 10 sec. was in 2 min., 13; in 40 min., 14; in 1 hour 15 min., 12; and in 1 hour 51 min., 12.—On the following day, it was 18; and on the 14th day, 24.	*With atropia*, in 9 min., and in 65 min., several fæcel pellets were passed. *After physostigma*, none. There was no defæcation, urination, nor salivation during the 2 hours of continuous observation.	*With atropia*, restlessness was caused, which had disappeared by 60 min. *After physostigma*, in 1 min. 30 sec., rare fibrillary twitches, which had ceased, without increasing, by 1 hour 14 min. In 20 min., distinct paralysis; in 40 min., very decided paralysis; and in 1 hour 50 min., distinct, though lessened, paralysis. Occasionally, there were some feeble tremors and irregular movements.
b	3 lbs. 5 oz.	0	0	0·13 (= about 0·12 gr. p. 3 lbs.)	—	Death, in 28 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Interval of Time (in minutes).	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
311.	3 lbs. 2 oz.	3·17	3	0·187	100	Death, in 57 min. after the administration of physostigma.	*With atropia*, in 7 min., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{18}{50} \times \frac{18}{50}$. In 98 min., the size was $\frac{18}{50} \times \frac{18}{50}$. *After physostigma*, the size was in 5 min., $\frac{18}{50} \times \frac{18}{50}$; in 13 min., $\frac{19}{50} \times \frac{19}{50}$; in 50 min., $\frac{10}{50} \times \frac{9}{50}$; and in 47 min., $\frac{18}{50} \times \frac{13}{50}$.—After death, it was in 6 min., $\frac{9}{50} \times \frac{9}{50}$; and in 1 hour 8 min., $\frac{10}{50} \times \frac{10}{50}$.	*With atropia*, in 5 min., acceleration from 38 to 60 per 10 sec. In 99 min., the rate per 10 sec. was 61. *After physostigma*, the rate per 10 sec. was in 4 min., 52; in 10 min., 31; in 41 min., 25; and in 43 min., 8.	*With atropia*, in 23 min., slowing to 15 per 10 sec.; and in 98 min. return to the normal rate of 22 per 10 sec. *After physostigma*, the rate per 10 sec. was in 5 min., 19; in 34 min., 13; and in 42 min., 10. Afterwards, only feeble gasps occurred irregularly until death.	*With atropia*, in 23 min., and in 35 min., several fæcal pellets were passed. There was no urination. *After physostigma*, in 14 min., in 39 min., and in 41 min., fæcal pellets were passed. In 14 min., and in 41 min., urine was freely voided. In 26 min., salivation commenced.	*With atropia*, in 34 min., restlessness, which had ceased by 30 min. *After physostigma*, in 1 min. 30 sec., rare fibrillary twitches, which soon became well marked, and continued for several min. after death. In 10 min., slight paralysis; and in 52 min., general flaccidity. Frequently, there were tremors, and now and then some convulsive movements.—Rigor began to set in at 1 hour 8 min. after death (temp. of laboratory, 58° F.).
312.	3 lbs. 12 oz.	3·75	3	0·22	105	Death, in 37 min. after the administration of physostigma.	*With atropia*, in 3 min., dilatation from $\frac{12}{50} \times \frac{12}{50}$ to $\frac{18}{50} \times \frac{19}{50}$. In 103 min., the size was $\frac{18}{50} \times \frac{19}{50}$. *After physostigma*, the size was in 10 min., $\frac{18}{50} \times \frac{19}{50}$; in 28 min., $\frac{20}{50} \times \frac{20}{50}$; and in 37 min., $\frac{20}{50} \times \frac{20}{50}$.—After death, it was in 2 min., $\frac{19}{50} \times \frac{19}{50}$; and in 35 min., $\frac{16}{50} \times \frac{17}{50}$.	*With atropia*, in 9 min., acceleration from 40 to 60 per 10 sec. In 104 min., the rate was 59 per 10 sec. *After physostigma*, the rate per 10 sec. was in 5 min., 44; in 19 min., 43; in 21 min., 29; in 28 min., 22; and in 32 min., 20. Afterwards, the impulse was so feeble that the rate could not be ascertained.	*With atropia*, in 75 min., acceleration from 16 to 37 per 10 sec. In 104 min., the rate was 38 per 10 sec. *After physostigma*, the rate per 10 sec. was in 4 min., 38; in 11 min., 18; in 14 min., 15; and in 20 min., 6. Afterwards, only feeble gasps occurred; in 24 min., 5; in 27 min., 2; and in 35 min., 1, per 10 sec.	*With atropia*, in 35 min., a large quantity of pultaceous fæces was passed. *After physostigma*, in 14 min., salivation commenced, but it did not become profuse. There was neither defæcation nor urination.	*With physostigma*, in 6 min., restlessness, which had ceased by 80 min. *After physostigma*, in 2 min., rare fibrillary twitches, which had ceased without increasing by 22 min. In 8 min., slight paralysis; and in 20 min., general flaccidity. Occasionally, there were some irregular movements of a doubtfully convulsive nature.—There was no appearance of rigor at 35 min. after death (temp. of laboratory, 58° F.).
313.	3 lbs. 1 oz.	3·06	3	0·183	120	Death, in 54 min. after the administration of physostigma.	*With atropia*, in 4 min., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{16}{50} \times \frac{16}{50}$. In 114 min., the size was $\frac{16}{50} \times \frac{16}{50}$. *After physostigma*, the size was in 5 min., $\frac{16}{50} \times \frac{16}{50}$; in 30 min., $\frac{16}{50} \times \frac{16}{50}$; and in 53 min., $\frac{16}{50} \times \frac{16}{50}$.—After death, it was in 1 min., $\frac{17}{50} \times \frac{17}{50}$; in 4 min., $\frac{14}{50} \times \frac{14}{50}$; in 14 min., $\frac{10}{50} \times \frac{10}{50}$; and in 46 min., $\frac{12}{50} \times \frac{12}{50}$.	*With atropia*, in 8 min., acceleration from 40 to 62 per 10 sec.. In 113 min., the rate was 63 per 10 sec. *After physostigma*, the rate per 10 sec. was in 5 min., 56; in 12 min., 48; in 26 min., 45; in 36 min., 25; in 47 min., 17; and in 51 min., 15. Afterwards, the impulse was so feeble that the rate could not be ascertained.	*With atropia*, in 2 min., acceleration from 19 to 20 per 10 sec. In 116 min., the rate was 23 per 10 sec. *After physostigma*, the rate per 10 sec. was in 3 min., 25; in 22 min., 15; in 36 min., 11; and in 46 min., 4. Afterwards, only gasps occurred, the rate per 10 sec. of which was in 50 min., 3; and in 53 min., 2.	*With atropia*, in 16 min., urine was freely voided. There was no defæcation. *After physostigma*, in 30 min., salivation commenced, and by-and-by became profuse. There was neither defæcation nor urination.	*With atropia*, in 8 min., restlessness, which had ceased by 40 min. *After physostigma*, in 2 min., rare fibrillary twitches, which became well marked, but ceased before death. In 7 min., slight paralysis; and in 45 min., general flaccidity. Tremors occurred frequently, and now and then there were some feeble spasms.—Rigor began to set in at about 46 min. after death.

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Interval of Time (in minutes).	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
314.	3 lbs.	4·5	4·5	0·18	10	Death, in 41 min. after the administration of physostigma.	*With atropia*, in 3 min., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{15}{50} \times \frac{15}{50}$; and in 7 min., to $\frac{16}{50} \times \frac{16}{50}$. *After physostigma*, the size was in 4 min., $\frac{16}{50} \times \frac{16}{50}$; in 20 min., $\frac{17}{50} \times \frac{17}{50}$; and in 40 min., $\frac{17}{50} \times \frac{17}{50}$.—After death, it was in 1 min., $\frac{16}{50} \times \frac{16}{50}$; in 31 min., $\frac{10}{50} \times \frac{9}{50}$; and in 1 hour 10 min., $\frac{11}{50} \times \frac{11}{50}$.	*With atropia*, in 9 min., acceleration from 40 to 60 per 10 sec. *After physostigma*, the rate per 10 sec. was in 4 min., 60; in 18 min., 58; in 25 min., 48; and in 31 min., 39.	*With atropia*, in 9 min. 30 sec., acceleration from 24 to 27 per 10 sec. *After physostigma*, the rate per 10 sec. was in 13 min., 23; in 20 min., 8; in 23 min., 7; and in 25 min., 5. Afterwards, only feeble gasps occurred irregularly.	*With atropia*, none. *After physostigma*, in 9 min., urine was freely voided. There was neither defæcation nor salivation.	*With atropia*, restless movements. *After physostigma*, in 1 min. 30 sec., rare fibrillary twitches, which soon became pretty well marked, but had ceased by 27 min. In 7 min., slight paralysis; and in 20 min., general flaccidity. Now and then, some feeble and somewhat spasmodic movements occurred.—Rigor began to set in at about 1 hour 11 min. after death (temp. of laboratory, 55° F.).
315. *a* [Experiment *b* was performed fifteen days after experiment *a*.]	3 lbs.	4·5	4·5	0·18	15	Recovery.	*With atropia*, in 4 min., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{16}{50} \times \frac{16}{50}$; and in 14 min., to $\frac{17}{50} \times \frac{17}{50}$. *After physostigma*, the size was in 5 min., $\frac{17}{50} \times \frac{17}{50}$; and in 1 hour 13 min., $\frac{17}{50} \times \frac{17}{50}$.—On the following day, it was $\frac{17}{50} \times \frac{17}{50}$; on the 9th day, $\frac{16}{50} \times \frac{16}{50}$; and on the 16th day, $\frac{14}{50} \times \frac{13}{50}$.	*With atropia*, in 5 min., acceleration from 38 to 54 per 10 sec. In 13 min., the rate was 59 per 10 sec. *After physostigma*, the rate per 10 sec. was in 13 min., 53; and in 1 hour 20 min., 50.—On the following day, it was 33; on the 3d day, 43; and on the 16th day, 40.	*With atropia*, in 13 min., acceleration from 19 to 25 per 10 sec. *After physostigma*, the rate per 10 sec. was in 5 min., 18; in 52 min., 11; and in 1 hour 21 min., 16.—On the following day, it was 15; and on the 16th day, 14.	*With atropia*, none. *After physostigma*, none. There was no defæcation, urination, nor salivation during the 1 hour 30 min. of continuous observation.	*With atropia*, restless movements. *After physostigma*, in 1 min. 30 sec., rare fibrillary twitches, which became well marked, and continued for more than 1 hour 20 min. In 10 min., slight paralysis; in 17 min., very decided paralysis; and in 1 hour 30 min., only slight paralysis. Occasionally, there were some sudden starts, chiefly of the head.
	b 3 lbs.	0	0	0·12	—	Death, in 19 min.	—	—	—	—	—
316. *a* [Experiment *b* was performed nine days after experiment *a*.]	3 lbs. 4 oz.	4·87	4·5	0·19	15	Recovery.	*With atropia*, in 2 min., dilatation from $\frac{13}{50} \times \frac{13}{50}$ to $\frac{15}{50} \times \frac{15}{50}$. In 14 min., the size was $\frac{16}{50} \times \frac{16}{50}$. *After physostigma*, the size was in 5 min., $\frac{16}{50} \times \frac{16}{50}$; in 1 hour, $\frac{16}{50} \times \frac{16}{50}$; and in 3 hours 45 min., $\frac{16}{50} \times \frac{17}{50}$.—On the following day, it was $\frac{18}{50} \times \frac{18}{50}$; on the 8th day, $\frac{12}{50} \times \frac{12}{50}$; and on the 10th day, $\frac{10}{50} \times \frac{9}{50}$.	*With atropia*, in 3 min., acceleration from 38 to 52 per 10 sec.; and in 14 min., to 59. *After physostigma*, the rate per 10 sec. was in 10 min., 63; in 40 min., 59; in 1 hour 37 min., 52; and in 3 hours 30 min., 39.—On the following day, it was 28; on the 3d day, 44; and on the 10th day, 39.	*With atropia*, none. The original rate was 20 per 10 sec. *After physostigma*, the rate per 10 sec. was in 4 min., 14; in 15 min., 22; in 1 hour 20 min., 12; in 1 hour 40 min., 10; and in 3 hours 52 min., 11.—On the following day, it was 10; and on the 10th day, 20.	*With atropia*, none. *After physostigma*, none. There was no defæcation, urination, nor salivation during the 3 hours 50 min. of continuous observation.	*With atropia*, restless movements. *After physostigma*, in 2 min., rare fibrillary twitches, which had ceased by 40 min. In 14 min., slight paralysis; in 50 min., very decided paralysis; and in 3 hours 30 min., only slight paralysis. Tremors occurred frequently.
	b 3 lbs. 5 oz.	0	0	0·135 (= 0·12 gr. p. 3 lbs.)	—	Death, in 21 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Interval of Time (in minutes).	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
317. [Experiment *b* was performed eight days after experiment *a*.]	3 lbs.	4·5	4·5	0·18	20	Recovery.	*With atropia*, in 3 min., dilatation from $\frac{14}{50}\times\frac{13}{50}$ to $\frac{16}{50}\times\frac{16}{50}$; and in 6 min., to $\frac{17}{50}\times\frac{17}{50}$. *After physostigma*, the size was in 7 min., $\frac{17}{50}\times\frac{17}{50}$; and in 2 hours, $\frac{17}{50}\times\frac{17}{50}$.—On the following day, it was $\frac{18}{50}\times\frac{19}{50}$; and on the 9th day, $\frac{18}{50}\times\frac{18}{50}$.	*With atropia*, in 4 min., acceleration from 35 to 55 per 10 sec.; and in 18 min., to 58 per 10 sec. *After physostigma*, the rate per 10 sec. was in 7 min., 56; in 15 min., 53; in 1 hour, 50; and in 2 hours, 43.—On the following day, it was 39; on the 7th day, 41; and on the 9th day, 38.	*With atropia*, in 17 min., acceleration from 21 to 24 per 10 sec. *After physostigma*, the rate per 10 sec. was in 5 min., 16; in 1 hour 2 min., 18; and in 1 hour 51 min., 23.—On the following day, it was 19; and on the 9th day, 19.	*With atropia*, in 18 min., several fæcal pellets were passed. *After physostigma*, none. There was no defæcation, urination, nor salivation during the 2 hours of continuous observation.	*With atropia*, restless movements. *After physostigma*, in 4 min. very rare fibrillary twitches, which had ceased, without increasing, by 17 min. In 15 min., slight paralysis; in 1 hour, very decided paralysis; and in 2 hours, decided, though lessened, paralysis. Occasionally, there were some feeble tremors.
b	3 lbs. 3 oz.	0	0	0·125 (= 0·12 gr. p. 3 lbs.)	—	Death, in 20 min.	—	—	—	—	—
318.	3 lbs. 1 oz.	5·1	5	0·18	15	Death, in 30 min. after the administration of physostigma.	*With atropia*, in 13 min., dilatation from $\frac{14}{50}\times\frac{13}{50}$ to $\frac{17}{50}\times\frac{17}{50}$. *After physostigma*, the size was in 7 min., $\frac{17}{50}\times\frac{17}{50}$; in 20 min., $\frac{18}{50}\times\frac{18}{50}$; and in 30 min., $\frac{18}{50}\times\frac{18}{50}$.—After death, it was in 2 min., $\frac{14}{50}\times\frac{14}{50}$; in 7 min., $\frac{10}{50}\times\frac{10}{50}$; and in 52 min., $\frac{12}{50}\times\frac{12}{50}$.	*With atropia*, in 14 min., acceleration from 43 to 63 per 10 sec. *After physostigma*, the rate per 10 sec. was in 3 min., 63; in 5 min., 56; in 22 min., 45; and in 29 min., 30.	*With atropia*, in 13 min., acceleration from 22 to 26 per 10 sec. *After physostigma*, the rate per 10 sec. was in 4 min., 17; in 17 min., 11; and in 20 min., 4. Afterwards, only feeble gasps occurred irregularly.	*With atropia*, none. *After physostigma*, none. There was no defæcation, urination, nor salivation.	*With atropia*, restlessness. *After physostigma*, in 1 min. 30 sec., rare fibrillary twitches, which ceased in a few minutes. In 9 min., distinct paralysis; and in 19 min., general flaccidity. Tremors and feeble spasms frequently occurred.—There was no appearance of rigor at 52 min. after death (temp. of laboratory, 60° F.).
319.	3 lbs. 10 oz.	6	5	0·217	20	Death, in 45 min. after the administration of physostigma.	*With atropia*, in 18 min., dilatation from $\frac{15}{50}\times\frac{14}{50}$ to $\frac{19}{50}\times\frac{19}{50}$. *After physostigma*, the size was in 9 min., $\frac{19}{50}\times\frac{19}{50}$; and in 44 min., $\frac{19}{50}\times\frac{19}{50}$.—After death, it was in 2 min., $\frac{15}{50}\times\frac{15}{50}$; and in 25 min., $\frac{10}{50}\times\frac{10}{50}$.	*With atropia*, in 8 min., acceleration from 40 to 63 per 10 sec. In 19 min., the rate was 61 per 10 sec. *After physostigma*, the rate per 10 sec. was in 4 min., 57; in 9 min., 50; in 30 min., 42; in 36 min., 39; and in 44 min. 30 sec., 26.	*With atropia*, in 18 min., acceleration from 30 to 34 per 10 sec. *After physostigma*, the rate per 10 sec. was in 18 min., 19; in 23 min., 11; in 25 min., 4; in 30 min., 7; and in 33 min., 1. Afterwards, only extremely feeble and rare respiratory movements occurred.	*With atropia*, several fæcal pellets were passed. *After physostigma*, none. There was no defæcation, urination, nor salivation.	*With atropia*, restlessness. *After physostigma*, in 2 min., rare fibrillary twitches, which had ceased by 27 min. In 15 min., distinct paralysis; in 20 min., very decided paralysis; and in 27 min., general flaccidity. Tremors and weak spasms occurred frequently.—There was no appearance of rigor at 25 min. after death.

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Interval of Time (in minutes).	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
320. *a* [Experiment *b* was performed sixteen days after experiment *a*.]	3 lbs. 4 oz.	5·41	5	0·195	25	Recovery.	*With atropia*, in 10 min., dilatation from $\frac{11}{50}\times\frac{10}{50}$ to $\frac{17}{50}\times\frac{17}{50}$. In 24 min., the size was $\frac{17}{50}\times\frac{17}{50}$. *After physostigma*, the size was in 10 min., $\frac{17}{50}\times\frac{17}{50}$; and in 1 hour 30 min., $\frac{18}{50}\times\frac{18}{50}$.—On the following day, it was $\frac{18}{50}\times\frac{18}{50}$; on the 4th day, $\frac{16}{50}\times\frac{16}{50}$; and on the 13th day, $\frac{11}{50}\times\frac{10}{50}$.	*With atropia*, in 5 min., acceleration from 44 to 60 per 10 sec. In 20 min., the rate was 61 per 10 sec. *After physostigma*, the rate per 10 sec. was in 9 min., 54; in 1 hour 10 min., 51; and in 1 hour 22 min., 53.—On the following day, it was 47; on the 6th day, 43; and on the 17th day, 40.	*With atropia*, in 17 min., acceleration from 26 to 40 per 10 sec. *After physostigma*, the rate per 10 sec. was in 7 min., 36; in 29 min., 22; in 1 hour, 18; in 1 hour 10 min., 14; and in 1 hour 23 min., 15.—On the following day, it was 29; on the 3d day, 33; and on the 17th day, 18.	*With atropia*, none. *After physostigma*, in 7 min., and in 1 hour 20 min., fæcal pellets were passed. There was neither urination nor salivation during the 1 hour 40 min. of continuous observation.	*With atropia*, restlessness. *After physostigma*, in 7 min., rare fibrillary twitches, which soon became well marked, and continued for more than 1 hour 20 min. In 20 min., slight paralysis; in 30 min., very decided paralysis; and in 1 hour 30 min., decided though diminished paralysis. Frequently, tremors occurred.
	b 3 lbs. 4 oz.	0	0	0·13 (= 0·12 gr. p. 3 lbs.)	—	Death, in 21 min.	—	—	—	—	—
321. *a* [Experiment *b* was performed twenty-one days after experiment *a*.]	3 lbs.	5	5	0·18	30	Recovery.	*With atropia*, in 5 min., dilatation from $\frac{12}{50}\times\frac{12}{50}$ to $\frac{17}{50}\times\frac{17}{50}$. In 28 min., the size was $\frac{17}{50}\times\frac{17}{50}$. *After physostigma*, the size was in 20 min., $\frac{17}{50}\times\frac{17}{50}$; in 1 hour, $\frac{17}{50}\times\frac{17}{50}$; and in 2 hours 30 min., $\frac{17}{50}\times\frac{17}{50}$.—On the following day, it was $\frac{17}{50}\times\frac{17}{50}$; on the 13th day, $\frac{16}{50}\times\frac{16}{50}$; and on the 22d day, $\frac{15}{50}\times\frac{14}{50}$.	*With atropia*, in 9 min., acceleration from 42 to 61 per 10 sec. In 29 min., the rate was 61 per 10 sec. *After physostigma*, the rate per 10 sec. was in 6 min., 54; in 50 min., 50; in 2 hours, 51; and in 2 hours 26 min., 53.—On the following day, it was 48; on the 6th day, 46; and on the 22d day, 41.	*With atropia*, in 28 min., slowing from 23 to 18 per 10 sec. *After physostigma*, the rate per 10 sec. was in 15 min, 14; in 1 hour 10 min., 13; and in 2 hours 25 min., 14.—On the following day, it was 23; on the 10th day, 30; and on the 22d day, 14.	*With atropia*, in 7 min., several normal fæcal pellets were passed. *After physostigma*, in 30 min., several normal fæcal pellets were passed. There was neither urination nor salivation during the 2 hours 30 min. of continuous observation.	*With atropia*, restlessness. *After physostigma*, in 6 min., rare fibrillary twitches, which had ceased by 20 min. In 27 min., slight paralysis; in 40 min., decided paralysis; and in 2 hours 30 min., only slight paralysis. Occasionally, there were some feeble tremors.
	b 3 lbs.	0	0	0·12	—	Death, in 25 min.	—	—	—	—	—
322. *a* [Experiment *b* was performed ten days after experiment *a*.]	3 lbs. 8 oz.	5·83	5	0·21	65	Recovery.	*With atropia*, in 62 min., dilatation from $\frac{10}{50}\times\frac{9}{50}$ to $\frac{16}{50}\times\frac{16}{50}$. *After physostigma*, the size was in 6 min., $\frac{10}{50}\times\frac{10}{50}$; and in 2 hours 10 min., $\frac{11}{50}\times\frac{11}{50}$.—On the 3d day, it was $\frac{11}{50}\times\frac{10}{50}$; and on the 11th day, $\frac{12}{50}\times\frac{12}{50}$.	*With atropia*, in 63 min., acceleration from 41 to 60 per 10 sec. *After physostigma*, the rate per 10 sec. was in 22 min., 58; in 1 hour 5 min., 50; and in 2 hours, 40.—On the 3d day, it was 31; and on the 11th day, 43.	*With atropia*, none. The original rate was 18 per 10 sec. *After physostigma*, the rate per 10 sec. was in 35 min., 18; in 1 hour, 14; and in 2 hours 5 min., 16.—On the 3d day, it was 16; and on the 11th day, 19.	*With atropia*, none. *After physostigma*, in 2 hours 5 min., several normal fæcal pellets were passed. There was neither urination nor salivation during the 2 hours 10 min. of continuous observation.	*With atropia*, restlessness, which had ceased by 35 min. *After physostigma*, in 19 min., pretty well marked fibrillary twitches, which continued for more than 2 hours. In 16 min., slight paralysis; in 40 min., very decided paralysis; and in 2 hours, only slight paralysis. Occasionally, there were tremors and spasms.
	b 3 lbs. 9 oz.	0	0	0·14 (= about 0·12 gr. p. 3 lbs.)	—	Death, in 37 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Interval of Time (in minutes).	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
323.	3 lbs. 2 oz.	5·2	5	0·19	65	Death, in 1 hour 10 min. after the administration of physostigma.	*With atropia*, in 62 min., dilatation from $\frac{14}{50} \times \frac{13}{50}$ to $\frac{17}{50} \times \frac{17}{50}$. *After physostigma*, the size was in 18 min., $\frac{18}{50} \times \frac{18}{50}$.	*With atropia*, in 15 min., acceleration from 39 to 60 per 10 sec. In 63 min., the rate was 59 per 10 sec. *After physostigma*, the rate per 10 sec. was in 10 min., 58; in 20 min., 56; and in 1 hour, 36.	*With atropia*, in 63 min., slowing from 22 to 16 per 10 sec. *After physostigma*, the rate per 10 sec. was in 7 min., 13; and in 1 hour, 3 (gasping).	*With atropia*, none. *After physostigma*, none. There was no defæcation, urination, nor salivation.	*With atropia*, in 4 min., restlessness, which had ceased by 55 min. *After physostigma*, in 16 min., slight paralysis; and in 30 min., general flaccidity. Frequently, there were tremors and spasms.
324.	3 lbs. 2 oz.	5·2	5	0·19	105	Death, in 56 min. after the administration of physostigma.	*With atropia*, in 10 min., dilatation from $\frac{13}{50} \times \frac{12}{50}$ to $\frac{16}{50} \times \frac{16}{50}$. In 104 min., the size was $\frac{16}{50} \times \frac{16}{50}$. *After physostigma*, the size was in 25 min., $\frac{16}{50} \times \frac{16}{50}$.	*With atropia*, in 6 min., acceleration from 42 to 59 per 10 sec. In 103 min., the rate was 56 per 10 sec. *After physostigma*, the rate per 10 sec. was in 6 min., 54; in 12 min., 49; in 43 min., 36; and in 55 min., 31.	*With atropia*, in 104 min., slowing from 23 to 18 per 10 sec. *After physostigma*, the rate per 10 sec. was in 10 min., 26; in 26 min., 22; in 36 min., 11; in 46 min., 5; and in 54 min., 3 (gasping).	*With atropia*, none. *After physostigma*, none.	*With atropia*, slight hypnosis. *After physostigma*, in 1 min. 30 sec., rare fibrillary twitches, which had ceased by 13 min. In 20 min., excited movements; in 22 min., slight paralysis; and in 36 min., general flaccidity. Frequently, there were tremors and general spasms.
325. [Experiment *b* was performed nine days after experiment *a*.]											
a	3 lbs. 6 oz.	5·83	5	0·21	105	Recovery.	*With atropia*, in 3 min., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{16}{50} \times \frac{16}{50}$. In 103 min., the size was $\frac{16}{50} \times \frac{16}{50}$. *After physostigma*, the size was in 2 hours 45 min., $\frac{16}{50} \times \frac{16}{50}$.—On the following day, it was $\frac{16}{50} \times \frac{16}{50}$; on the 4th day, $\frac{16}{50} \times \frac{16}{50}$; and on the 10th day, $\frac{15}{50} \times \frac{14}{50}$.	*With atropia*, in 30 min., acceleration from 41 to 60 per 10 sec. In 104 min., the rate was 57 per 10 sec. *After physostigma*, the rate per 10 sec. was in 6 min., 55; in 1 hour 10 min., 60; and in 2 hours 44 min., 44.—On the following day, it was 35; on the 4th day, 42; and on the 10th day, 39.	*With atropia*, in 31 min., slowing from 36 to 30 per 10 sec.; and in 104 min., to 14 per 10 sec. *After physostigma*, the rate per 10 sec. was in 14 min., 15; in 1 hour 15 min., 15; in 2 hours, 17; and in 2 hours 46 min., 18.—On the following day, it was 18; on the 4th day, 31; and on the 10th day, 15.	*With atropia*, none. *After physostigma*, in 2 hours, urine was freely voided. There was neither defæcation nor salivation during the 2 hours 50 min. of continuous observation.	*With atropia*, in 4 min., restlessness, which had ceased by 90 min. *After physostigma*, in 4 min., rare fibrillary twitches, which became well marked, and continued for more than 2 hours 45 min. In 8 min., slight paralysis; in 25 min., very advanced paralysis; and in 2 hours 50 min., only slight paralysis. Occasionally, there were some tremors.
b	3 lbs. 6 oz.	0	0	0·135 (= 0·12 gr. p. 3 lbs.)	—	Death, in 30 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Interval of Time (in minutes).	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
326. [Experiment *b* was performed twelve days after experiment *a*.]											
a	3 lbs. 5 oz.	5·52	5	0·2	140	Recovery.	*With atropia*, in 7 min., dilatation from $\frac{14}{50} \times \frac{14}{50}$ to $\frac{16}{50} \times \frac{16}{50}$. In 135 min., the size was $\frac{15}{50} \times \frac{15}{50}$. *After physostigma*, the size was in 5 min., $\frac{15}{50} \times \frac{15}{50}$; in 1 hour, $\frac{15}{50} \times \frac{16}{50}$; and in 1 hour 30 min., $\frac{15}{50} \times \frac{15}{50}$.—On the following day, it was $\frac{17}{50} \times \frac{17}{50}$; on the 3d day, $\frac{17}{50} \times \frac{17}{50}$; and on the 13th day, $\frac{15}{50} \times \frac{14}{50}$.	*With atropia*, in 8 min., acceleration from 42 to 60 per 10 sec. The rate per 10 sec. was in 110 min., 52; and in 136 min., 52. *After physostigma*, the rate per 10 sec. was in 4 min., 48; in 40 min., 47; and in 1 hour 20 min., 49.—On the following day, it was 48; on the 3d day, 46; and on the 13th day, 42.	*With atropia*, in 40 min., slowing from 29 to 19 per 10 sec. In 137 min., the rate was 23 per 10 sec. *After physostigma*, the rate per 10 sec. was in 8 min., 21; in 45 min., 15; and in 1 hour 15 min., 13.—On the following day, it was 30; and on the 13th day, 22.	*With atropia*, none. *After physostigma*, none. There was no defæcation, urination, nor salivation during the 1 hour 30 min. of continuous observation.	*With atropia*, in 7 min., restlessness, which had ceased by 38 min. *After physostigma*, in 5 min. 30 sec., rare fibrillary twitches, which soon became well marked, and continued so for more than 1 hour. In 19 min., distinct paralysis; in 50 min., very advanced paralysis; and in 1 hour 30 min., advanced paralysis. There were neither tremors nor spasms.
b	3 lbs. 4 oz.	0	0	0·13 (= 0·12 gr. p. 3 lbs.)	—	Death, in 24 min.	—	—	—	—	—
327. [Experiment *b* was performed twelve days after experiment *a*.]											
a	3 lbs. 6 oz.	5·62	5	0·2	170	Recovery.	*With atropia*, in 10 min., dilatation from $\frac{13}{50} \times \frac{11}{50}$ to $\frac{17}{50} \times \frac{17}{50}$. In 165 min., the size was $\frac{16}{50} \times \frac{16}{50}$. *After physostigma*, the size was in 1 hour 30 min., $\frac{16}{50} \times \frac{16}{50}$.—On the following day, it was $\frac{17}{50} \times \frac{17}{50}$; and on the 13th day, $\frac{15}{50} \times \frac{15}{50}$.	*With atropia*, in 9 min., acceleration from 41 to 60 per 10 sec. In 166 min., the rate was 60 per 10 sec. *After physostigma*, the rate per 10 sec. was in 8 min., 60; in 12 min., 46; in 50 min., 49; in 1 hour, 46; and in 1 hour 30 min., 43.—On the following day, it was 47; and on the 13th day, 40.	*With atropia*, in 6 min., slowing from 23 to 17 per 10 sec.; and in 165 min., to 15 per 10 sec. *After physostigma*, the rate per 10 sec. was in 10 min., 17; in 40 min., 20; and in 1 hour 29 min., 14.—On the following day, it was 20; and on the 13th day, 19.	*With atropia*, none. *After physostigma*, none. There was no defæcation, urination, nor salivation during the 1 hour 35 min. of continuous observation.	*With atropia*, in 10 min., restlessness, which had ceased by 40 min. *After physostigma*, in 3 min., rare fibrillary twitches, which continued thus for more than 1 hour 30 min. In 12 min., slight paralysis; in 40 min., very decided paralysis; and in 1 hour 30 min., also very decided paralysis. Frequently, there were tremors and irregular spasmodic movements.
b	3 lbs. 5 oz.	0	0	0·13 (= 0·12 gr. p. 3 lbs.)	—	Death, in 21 min.	—	—	—	—	—

Number of Experiment.	Weight of Rabbit.	phate of Atropia (in Grains). Actual Dose.	phate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	sostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Interval of Time (in minutes).	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
328. *a* [Experiment *b* was performed nine days after experiment *a*.]	3 lbs. 11 oz.	6·1	5	0·22	175	Recovery.	*With atropia*, in 4 min., dilatation from $\frac{15}{50}\times\frac{14}{50}$ to $\frac{18}{50}\times\frac{18}{50}$. In 174 min., the size was $\frac{18}{50}\times\frac{18}{50}$. *After physostigma*, the size was in 5 min., $\frac{9}{50}\times\frac{10}{50}$.—The size was not again noted until the following day, when it was $\frac{18}{50}\times\frac{18}{50}$; on the 6th day, it was $\frac{18}{50}\times\frac{18}{50}$; and on the 10th day, $\frac{16}{50}\times\frac{15}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 41 to 60 per 10 sec. In 173 min., the rate was 54 per 10 sec. *After physostigma*, the rate per 10 sec. was in 4 min., 50; in 23 min., 54; in 40 min., 37; and in 1 hour 30 min., 33.—On the following day, it was 42; on the 6th day, 40; and on the 10th day, 39.	*With atropia*, in 20 min., slowing from 27 to 24 per 10 sec. In 174 min., the rate was 15 per 10 sec. *After physostigma*, the rate per 10 sec. was in 3 min., 16; in 28 min., 14; in 40 min., 22; and in 1 hour 25 min., 20.	*With atropia*, in 75 min., and in 173 min., fæcal pellets were passed. There was no urination. *After physostigma*, in 5 min., in 49 min., in 1 hour 20 min., and in 1 hour 35 min., several fæcal pellets were passed. In 1 hour 20 min., and in 1 hour 35 min., urine was freely voided. In 50 min., salivation commenced, which continued until after 1 hour 35 min., and was accompanied with noisy respirations.	*With atropia*, no obvious effect. *After physostigma*, in 1 min. 30 sec., rare fibrillary twitches, which soon became well marked, and continued so for more than 1 hour 25 min. In 10 min., slight paralysis; in 45 min., very advanced paralysis; and in 1 hour 35 min., distinct, though diminished paralysis. Occasionally, there were some feeble tremors.
b	3 lbs. 10 oz.	0	0	0·145 (= 0·12 gr. p. 3 lbs.)	—	Death, in 25 min.	—	—	—	—	—
329.	3 lbs.	5	5	0·18	180	Death, in 53 min. after the administration of physostigma.	*With atropia*, in 10 min., dilatation from $\frac{11}{50}\times\frac{10}{50}$ to $\frac{16}{50}\times\frac{16}{50}$. In 177 min., the size was $\frac{15}{50}\times\frac{15}{50}$. *After physostigma*, the size was in 7 min., $\frac{15}{50}\times\frac{15}{50}$; in 45 min., $\frac{17}{50}\times\frac{17}{50}$; and in 52 min., $\frac{17}{50}\times\frac{17}{50}$.—After death, it was in 1 min., $\frac{16}{50}\times\frac{16}{50}$; in 10 min., $\frac{14}{50}\times\frac{14}{50}$; and 53 min., $\frac{15}{50}\times\frac{15}{50}$.	*With atropia*, in 4 min., acceleration from 44 to 60 per 10 sec. In 178 min., the rate was 62 per 10 sec. *After physostigma*, the rate per 10 sec. was in 4 min., 55; in 6 min., 50; in 32 min., 52; in 45 min., 42; in 50 min., 26; and in 52 min., 24.	*With atropia*, in 11 min., acceleration from 27 to 32 per 10 sec. In 177 min., the rate was 15 per 10 sec. *After physostigma*, the rate per 10 sec. was in 8 min., 11; in 28 min., 14; in 34 min., 11; and in 45 min., 5. Afterwards, only laboured gasps occurred.	*With atropia*, none. *After physostigma*, none. There was no defæcation, urination, nor salivation.	*With atropia*, in 10 min., restlessness, which had ceased by 50 min. *After physostigma*, no fibrillary twitches were detected. In 12 min., distinct paralysis; and in 36 min., general flaccidity. Frequently, there were tremors and feeble spasms.—Rigor began to set in at about 50 min. after death (temp. of laboratory, 58° F.).
330.	3 lbs. 10 oz.	6·04	6	0·217	185	Death, in 43 min. after the administration of physostigma.	*With atropia*, in 7 min., dilatation from $\frac{15}{50}\times\frac{14}{50}$ to $\frac{17}{50}\times\frac{17}{50}$. In 180 min., the size was $\frac{18}{50}\times\frac{18}{50}$. *After physostigma*, the size was in 6 min., $\frac{18}{50}\times\frac{18}{50}$; in 34 min., $\frac{18}{50}\times\frac{18}{50}$; in 57 min., $\frac{19}{50}\times\frac{19}{50}$; and in 42 min., $\frac{20}{50}\times\frac{20}{50}$.—After death, it was in 2 min., $\frac{19}{50}\times\frac{19}{50}$; in 7 min., $\frac{16}{50}\times\frac{15}{50}$; and in 47 min., $\frac{15}{50}\times\frac{15}{50}$.	*With atropia*, in 25 min., acceleration from 36 to 62 per 10 sec. In 183 min., the rate was 57 per 10 sec. *After physostigma*, the rate per 10 sec. was in 5 min., 49; in 9 min., 43; in 20 min., 41; and in 30 min., 25. The impulse could not be felt after 34 min. With the stethescope, in 35 min., the rate was found to be 18 per 10 sec.	*With atropia*, in 7 min., slowing from 21 to 16 per 10 sec. In 181 min., the rate was 13 per 10 sec. *After physostigma*, the rate per 10 sec. was in 8 min., 18; in 28 min., 10; and in 32 min., 8. Afterwards, only feeble and noisy gasps occurred.	*With atropia*, none. *After physostigma*, in 25 min., salivation commenced, and the respirations became noisy. There was neither defæcation nor urination.	*With atropia*, restlessness. *After physostigma*, in 3 min., rare fibrillary twitches, which soon became well marked, and continued for several min. after death. In 13 min., slight paralysis; and in 32 min., general flaccidity. Tremors occured frequently.—There was no appearance of rigor at 47 min. after death (temp. of laboratory, 58° F.).

Number of Experiment.	Weight of Rabbit.	Doses of Sulphate of Atropia (in Grains). Actual Dose.	Doses of Sulphate of Atropia (in Grains). Dose p. 3 lbs. of Animal.	Dose of Physostigma (in Grains). Actual Dose of Sul. of Physostigmia.	Interval of Time (in minutes).	Result.	Effect on the Pupils. (The Measurements are in fiftieths of an inch.)	Effect on the Heart.	Effect on the Respirations.	Effect on Secretion and Excretion.	Effects on Motility, &c.
331.	3 lbs. 4 oz.	5·41	5	0·195	200	Death, in 1 hour 6 min. after the administration of physostigma.	*With atropia*, in 4 min., dilatation from $\frac{12}{50} \times \frac{11}{50}$ to $\frac{17}{50} \times \frac{17}{50}$. In 195 min., the size was $\frac{17}{50} \times \frac{17}{50}$. *After physostigma*, the size was in 30 min., $\frac{17}{50} \times \frac{17}{50}$; in 45 min., $\frac{17}{50} \times \frac{17}{50}$; and in 1 hour 5 min., $\frac{17}{50} \times \frac{17}{50}$.—After death, it was in 2 min., $\frac{15}{50} \times \frac{15}{50}$; in 3 min., $\frac{14}{50} \times \frac{14}{50}$; and in 14 min., $\frac{10}{50} \times \frac{10}{50}$.	*With atropia*, in 4 min. 30 sec., acceleration from 39 to 57 per 10 sec. In 198 min., the rate was 52 per 10 sec. *After physostigma*, the rate per 10 sec. was in 5 min., 51; in 14 min., 40; in 25 min., 39; in 35 min., 36; in 45 min., 30; in 55 min., 23; and in 1 hour 3 min. 30 sec., 16 (very feeble).	*With atropia*, in 8 min., acceleration from 27 to 38 per 10 sec. In 197 min., the rate was 16 per 10 sec. *After physostigma*, the rate per 10 sec. was in 5 min., 15; in 25 min., 11; in 46 min., 10 (noisy); and in 1 hour 3 min., 8. Afterwards, only gasps occurred.	*With atropia*, none. *After physostigma*, in 16 min., in 32 min., and in 51 min., urine was voided. In 51 min., and in 1 hour 3 min., semi-liquid fæces were passed. In 25 min., salivation commenced and continued until death.	*With atropia*, in 4 min., restlessness, which had ceased by 50 min. *After physostigma*, in 5 min., rare fibrillary twitches, which became well marked, and continued for several minutes after death. In 8 min., slight paralysis; and in 25 min., general flaccidity. There were neither tremors nor spasms.—There was no appearance of rigor at 14 min. after death (temp. of laboratory, 55° F.).

EXPLANATION OF PLATES XXIII., XXIV., AND XXV.

In each of the diagrams represented in these plates, the experiments that terminated in recovery are marked by dots, and those that terminated in death by crosses; and a line (distinguished in several of the diagrams as *a b c*) has been drawn so as to separate the dots from the crosses. The area on the side of the line where the dots occur has been coloured pink, while the area on the side where the crosses occur has been coloured blue; and, accordingly, the pink area represents the region of recovery, and the blue area the region of death. In the diagrams of Plates XXIII. and XXIV., the red horizontal line indicates the position of the minimum-lethal dose of physostigma.

Plate XXIII.

Diagram 1 illustrates the first series of experiments, in which atropia in varying doses was administered five minutes *before* varying doses of physostigma.

Diagram 2 illustrates the small portion of the first series that extends to ·2 gr. of sulphate of atropia. It is drawn on a different scale from Diagram 1, as each tenth of a grain of sulphate of atropia is indicated by twenty in place of by two subdivisions of the horizontal lines.

Diagram 3 illustrates the second series of experiments, in which atropia in varying doses was administered five minutes *after* varying doses of physostigma.

Diagram 4 illustrates the small portion of the second series of experiments that extends to ·2 gr. of sulphate of atropia; and the scale on which it has been drawn differs from that of Diagram 3 to the same extent as the scale of Diagram 2 differs from that of Diagram 1.

Diagrams 1 and 3 are mainly designed to illustrate the experiments extending from the minimum-lethal dose of physostigma to the largest dose that can be counteracted successfully by atropia. They have been drawn on the same scale in order that the results of the two series of experiments represented by them may be compared. Diagrams 2 and 4 exhibit the course of the line *a b* in the first and second series of experiments respectively, with greater distinctness and accuracy than Diagrams 1 and 3.

Plate XXIV.

Diagram 5 illustrates the first series of experiments; but it differs from Diagrams 1 and 2 in so far that the entire region of recovery (pink) is represented, and that each subdivision of the horizontal lines indicates a tenth in place of a twentieth of a grain of sulphate of atropia. The perpendicular red line marks the position of the minimum-lethal dose of sulphate of atropia.

The main purpose of this diagram is to show what combinations of atropia with less than the minimum-lethal dose of physostigma are able to produce death. These combinations are represented in the blue region below the red horizontal line.

Plate XXV.

Diagram 6 illustrates the third series of experiments, in which the dose of physostigma was constant (one and a half times the minimum-lethal dose), while the dose of atropia and the interval of time varied. In this diagram, as in Diagrams 1 and 3, each subdivision of the horizontal lines represents one-twentieth of a grain of sulphate of atropia. The intervals of time are represented by distance in a perpendicular direction from the thick horizontal line, which indicates the zero interval or simultaneous administration; and points below this line indicate atropia administered *after* physostigma, while points above it indicate atropia administered *before* physostigma.

XXII.—*On the Decomposition of Forces externally applied to an Elastic Solid.*

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Introductory Remarks.—The principles set forth in this paper, though now (with the exception of the first theorem) published for the first time, were communicated to the French Academy of Sciences fifteen years ago, in a memoir entitled "De l'Equilibre intérieur d'un Corps solide, élastique, et homogène," and marked with the motto, "Obvia conspicimus, nubem pellente Mathesi," the receipt of which is acknowledged in the *Comptes Rendus* of the 6th April 1857.

(1.) *Principle of Isorrhopic Axes.*—The following theorem was first published in the "Philosophical Magazine" for December 1855.

Prop. I. "*Theorem.* Every self-balanced system of forces applied to a connected system of points is capable of resolution into three rectangular systems of parallel self-balanced forces applied to the same points.

"*Demonstration.*—Assume any set of rectangular axes, to which reduce the forces and the positions of their points of application; and let X, Y, Z be the components of the force applied to any point $(x\ y\ z)$."

"Let

$$\Sigma . Xx = A\ ;\ \Sigma . Yy = B\ ;\ \Sigma . Zz = C\ ;\ \Sigma . Yx = \Sigma . Zy = D\ ;\ \Sigma . Zx = \Sigma . Xx = E\ ;\ \Sigma . Xy = \Sigma . Yx = F.$$

Then, in linear transformations of rectangular co-ordinates, A is covariant with $\underline{x^2}$, D with $\underline{yz}$, &c.

"Conceive the surface of the second order, whose equation is

$$Ax^2 + By^2 + Cz^2 + 2Dyz + 2Ezx + 2Fxy = \text{constant} \quad . \quad (1).$$

Then if the forces, and the positions of their points of application be reduced anew to the principal axes of that surface, we shall have

$$D = 0,\ E = 0,\ F = 0\ ;$$

and consequently, each of the three systems of component forces parallel to

those three principal axes will be self-balanced, independently of the other two systems. *Q. E. D.*"*

Remark.—The values of A, B, &c., obviously depend solely on the directions of the axes, and not on their point of intersection.

(2.) *Definitions.*—The following terms will be employed in the sequel, relatively to any given system of forces.

Rhopimetric Surface.—The surface (1).

Rhopimetric Co-efficients.—The quantities A, B, C, D, E, F.

Isorrhopic Axes.—The principal axes of the surface (1).

Principal Rhopimetric Co-efficients.—The values of the co-efficients A, B, C, for the isorrhopic axes.

Arrhopic System.—A system of forces for which $A = 0$, $B = 0$, $C = 0$, $D = 0$, $E = 0$, $F = 0$; and for which, consequently, every direction is an isorrhopic axis.

(3.) *Application to Elastic Solids.*—The utility of the above principle of isorrhopic axes in the theory of the equilibrium of elastic solids arises from the fact, that although, in treating of the equilibrium of a solid body as a whole supposed to be perfectly rigid, it is allowable to suppose the point of application of any force to be anywhere in the line of action of that force; yet, when the solid body is considered as being *strained* by the forces applied to it, no such supposition is admissible; and in every mathematical process for determining such straining effect the actual point of application of each force must alone be considered. When the straining forces to which an elastic solid is subjected are restricted within certain limits, the straining effect of any number of self-balanced systems of forces combined is sensibly equal to the sum of the effects which those systems respectively produce when acting separately.

Consequently, the principle of Isorrhopic Axes affords the means of reducing the problem of finding the straining effect of any self-balanced system of forces applied to an elastic solid to that of finding the separate straining effects of three self-balanced systems of parallel forces.

Prop. II.—Problem. *To find the Rhopimetric Co-efficients for a system of Forces applied over the surface and throughout the interior of a solid body.*

Let X, Y, Z, denote the components of the attractive or repulsive accelerative force applied to a molecule of the solid whose co-ordinates are $\underline{x}, \underline{y}, \underline{z}$, its volume $\underline{dx\ dy\ dz}$, and its density ρ; let P, Q, R, denote the components of the external stress (tension positive) per unit, of area, which acts on an element

* It is easy to see how this theorem may be extended to a system of moving masses, by putting $X - m\frac{d^2x}{dt^2}$ for X, &c.

of the external surface of the solid whose co-ordinates are x', y', z, and area d^2s; then

$$\left.\begin{aligned} A &= \iiint x X\rho \,.\, dx\,dy\,dz + \iint x' P d^2s\,; \\ D &= \iiint z Y\rho \,.\, dx\,dy\,dz + \iint z' Q \,.\, d^2s \\ &= \iiint y Z\rho \,.\, dx\,dy\,dz + \iint y' R \,.\, d^2s \end{aligned}\right\} \quad . \quad . \quad (2),$$

and the expressions for the other co-efficients will be similar, *mutatis mutandis*. *Q. E. I.*

In the case of normal external stress, let n_x, n_y, n_z be the direction-cosines of the normal to the element d^2s, and S the intensity of normal stress on that element; then

$$P = Sn_x\,;\ Q = Sn_y\,;\ R = Sn_z\,;$$

and in finding the values of the double integrals, we may put $n_x\, d^2s = dy\, dz$, &c.; observing, that for each set of an even number of elements d^2s, which have a common projection such as $dy\, dz$, the quantity to be integrated is of a form such as $\Sigma S x'$, and contains as many terms as there are elements having a common projection; the sign of each term being positive or negative, according as the direction-cosine (as n_x) is positive or negative.

(4.) *Summary of the Relations between Internal Stresses and Applied Forces in an Elastic Solid in Equilibrio.*

The following principles having been long known through the investigations of various mathematicians, are here recapitulated for the sake of convenience. In expressing internal stresses, the notation of M. Lamè is adopted, viz., let $dx\, dy\, dz$ be a rectangular molecule, and let

$$N_x\,,\ N_y\,,\ N_z\,,$$

be the *normal stresses per unit of area*, on the *pairs of faces* normal respectively to

$$x,\ y,\ z\,,$$

such stresses being considered as *positive* when *tensile*, *negative* when compressive. Also, let

$$T\,,\ T_y,\ T_z\,,$$

be the *tangential stresses per unit of area* on the *double pairs of faces* parallel respectively to

$$x,\ y,\ z\,.$$

T_x being considered as positive when it tends to elongate the positive and shorten the negative diagonal of the faces $\perp x$, &c. In the transformation of co-ordinates, N_x, N_y, N_z, T_x, T_y, T_z, are covariant respectively with x^2, y^2, z^2, yz, zx, xy. Let n_x, n_y, n_z, be the direction-cosines of the external normal to any point of the body's surface.

Then the following are the conditions of equilibrium between the internal stresses and the applied forces.

Conditions relative to each Internal Molecule:—

$$\left.\begin{aligned} \frac{dN_x}{dx} + \frac{dT_z}{dy} + \frac{dT_y}{dz} + \rho X = 0\,; \\ \frac{dT_z}{dx} + \frac{dN_y}{dy} + \frac{dT_x}{dz} + \rho Y = 0\,; \\ \frac{dT_y}{dx} + \frac{dT_x}{dy} + \frac{dN_z}{dz} + \rho Z = 0\,. \end{aligned}\right\} \quad . \quad . \quad (3).$$

Conditions relative to each Point of the Surface:—

$$\left.\begin{aligned} P &= n_x N_x + n_y T_z + n_z T_y \\ Q &= n_x T_z + n_y N_y + n_z T_x \\ R &= n_x T_y + n_y T_x + n_z N_z \end{aligned}\right\} \quad . \quad . \quad (4).$$

(5.) *Effect of Terrestrial Gravitation.*—In a homogeneous heavy body near the earth's surface, the internally applied forces ρX, ρY, ρZ, are constants, being simply the components of the weight of unity of volume of the body along the three axes of co-ordinates.

PROP. III.—PROBLEM. *To Balance the Weight of a Homogenous Body by Pressure applied to its Surface, so as to form an Arrhopic System of Forces; and to Determine the corresponding Internal Stresses.*—Assume a vertical direction positive downwards, for the axis x, and let the plane of yz pass through the centre of gravity of the body; then $\rho Y = 0$, $\rho Z = 0$; and $\rho X = g\rho$ is the weight of unity of volume of the body. For the applied external pressures, make $Q_g = 0$, $R_g = 0$,

$$P_g = -g\rho x' n_x\,; \quad . \quad . \quad . \quad . \quad . \quad . \quad (5).$$

Then the system of pressures P_g balances the weight of the body; for let the horizontal projection of an element d^2s of the body's surface be $dy\,dz$, then $d^2s = \frac{dy\,dz}{n_x}$; and that projection is to be considered as positive or negative according to the sign of n_x; consequently

$$\iint P d^2s = -g\rho \iint x'\,dy\,dz = -g\rho V.$$

where V is the entire volume of the body. Also the entire system of forces is Arrhopic. For it is evident that

$$B = C = D = E = F = 0;$$

and

$$A = g\rho\{\iiint x\,dx\,dy\,dx - \iint x'^2 dy\,dz\}.$$

Now the first term of the above expression is well known to be null when the plane yz traverses the centre of gravity; and by attending to the rule, that $dydz$ is positive or negative according to the sign of n_x, it appears that the second term is null also. Therefore, $A = 0$, and the system of forces is Arrhopic.

Lastly, for the system of internal stresses, make

$$N_{y\cdot g} = 0;\ N_{z\cdot g} = 0;\ T_{x\cdot g} = 0;\ T_{y\cdot g} = 0;\ T_{z\cdot g} = 0;\ N_{x\cdot g} = -g\rho x \quad . \quad (6).$$

This system evidently satisfies equations 3, 4, and 5; that is to say, the required system of internal stresses consists in a vertical normal stress at each molecule, proportional to its vertical distance from the horizontal plane of the centre of gravity of the body, tensile above that plane, and compressive below. *Q. E. I.*

Definitions.—*Antibarytic Pressures:* the externally applied pressures which (as in the above problem) form, with the gravitation of a body, an Arrhopic system. *Antibarytic Stresses:* the corresponding internal stresses.

Remark.—It is characteristic of the Antibarytic pressures that their intensity *for each unit of area of the horizontal projection of the body's surface* is a linear function of the vertical co-ordinate, viz.,

$$\frac{P_g}{n_x} = -g\rho x' \quad . \quad . \quad . \quad . \quad . \quad . \quad (6A).$$

Abarytic Pressures.—The system of pressures left after taking away the Antibarytic Pressures from the Actual Pressures applied at the several elements of the body's surface.

Corollary.—The Abarytic Pressures are self-balanced; their Rhopimetric co-efficients are the same with those of the entire system of Applied Forces; and in calculating their effects, the force of gravity is to be left out of consideration. Hence the internal stresses corresponding to a system of Abarytic Pressures must fulfil the following equations:—

$$\left.\begin{aligned} \frac{dN_x}{dx} + \frac{dT_z}{dy} + \frac{dT_y}{dz} &= 0; \\ \frac{dT_z}{dx} + \frac{dN_y}{dy} + \frac{dT_x}{dz} &= 0; \\ \frac{dT_y}{dx} + \frac{dT_x}{dy} + \frac{dN_z}{dz} &= 0; \end{aligned}\right\} \quad . \quad . \quad (7).$$

(6.) *Decomposition of Abarytic Pressures.*

DEFINITION.—*Homalotatic System of Pressures:* A system of Abarytic Pressures applied to the surface of a body, and producing an uniform state of stress throughout its internal molecules.

PROP. IV.—PROBLEM. *To Decompose any Abarytic System of Pressures applied to the Surface of a Solid into a Homalotatic System, and an Arrhopic System.*

Having computed the six Rhopimetric co-efficients for the given Abarytic system of Pressures, as referred to any set of orthogonal axes, take the following values for a set of six uniform internal stresses; V being (as in Proposition III.) the volume of the solid :—

$$\left.\begin{aligned} N_{x\cdot 0} &= \frac{A}{V}\ ;\ N_{y\cdot 0} = \frac{B}{V}\ ;\ N_{z\cdot 0} = \frac{C}{V}\ ; \\ T_{x\cdot 0} &= \frac{D}{V}\ ;\ T_{y\cdot 0} = \frac{E}{V}\ ;\ T_{z\cdot 0} = \frac{F}{V}\ ; \end{aligned}\right\} \quad . \quad . \quad (8).$$

These quantities being constant, fulfil equation (7).

The corresponding external pressures are as follows, according to equation (4) :—

$$\left.\begin{aligned} P_0 &= \frac{1}{V}\left\{ n_x A + n_y F + n_z E \right\} \\ Q_0 &= \frac{1}{V}\left\{ n_x F + n_y B + n_z D \right\} \\ R_0 &= \frac{1}{V}\left\{ n_x E + n_y D + n_z C \right\} \end{aligned}\right\} \quad . \quad . \quad (9).$$

If the Homalotatic system of pressures given by these equations be taken from the entire Abarytic system, an Arrhopic system will remain.

For the Rhopimetric co-efficients corresponding to the Homalotatic pressures are as follows :—

$$\begin{aligned} A_0 &= \iint x' P_0 d^2 s \\ &= \frac{1}{V}\left\{ A\iint x'\,dy\,dz + F\iint x'\,dz\,dx + E\iint x'\,dx\,dy \right\} \end{aligned}$$

(and similar equations for the others, *mutatis mutandis*).

Now, observing as before, that

$$dy\,dz,\ dz\,dx,\ dx\,dy$$

are to be considered positive or negative according to the sign of

$$n_x,\ n_y,\ n_z,$$

it appears that

$$\iint x' dy dz = \mathrm{V} \; ; \; \iint x' dz dx = 0 \; ; \; \iint x' dy dz = 0 \; ;$$

so that

$$\mathrm{A}_0 = \mathrm{A} \; ;$$

and in like manner, each of the Rhopimetric co-efficients for the system of Homalotatic Pressures is proved to be equal to the corresponding co-efficient for the entire system of Abarytic Pressures; so that the system of residual pressures, left after taking away the Homalotatic Pressure from the Abarytic Pressures, is *Arrhopic.* *Q. E. F.*

Remark.—The Homalotatic system of six uniform stresses obviously represents the *mean state of stress* of the whole body.

Corollary.—The set of six uniform stresses given by equation (8) are equivalent to three principal rectangular uniform normal stresses along the Isorrhopic Axes. For the three principal normal stresses of the system (8) are in direction parallel to, and in magnitude represented by, the reciprocals of the squares of the principal semi-axes of the surface,

$$\mathrm{N}_{x \cdot 0} x^2 + \mathrm{N}_{y \cdot 0} y^2 + \mathrm{N}_{z \cdot 0} z^2$$

$$+ 2\mathrm{T}_{x \cdot 0} yz + 2\mathrm{T}_{y \cdot 0} zx + 2\mathrm{T}_{z \cdot 0} xy = 1 \; ; \qquad . \qquad . \qquad (10),$$

which is similar and parallel to the Rhopimetric surface.

(7.) *Recapitulation, and Statement of the Advantages of the Method described.*—The following is a summary of the processes of the before-described method of decomposing any self-balanced system of forces applied to an Elastic Solid near the earth's surface:—

First. By Proposition II. Equation 2, find the six *Rhopimetric Co-efficients* of the system of applied forces, including gravitation.

Secondly. By Proposition III. Equations 5, 6, compute the system of vertical *Antibarytic Pressures,* with their corresponding vertical internal stresses; which pressures at once balance the force of gravitation, and form with it an Arrhopic system.

Thirdly. Take away from the entire pressure applied at each element of the body's surface the Antibarytic pressure at the same element, so as to leave a system of *Abarytic Pressures,* which is self-balanced, independently of gravitation, and whose Rhopimetric co-efficients are the same with those originally computed.

Fourthly. By Proposition IV. Equations 8 and 9, compute from the given set of Rhopimetric co-efficients the system of *six uniform mean internal stresses,* with the corresponding system of *Homalotatic external pressures.*

Fifthly. Take away from the Abarytic pressure on each element of the

body's surface, left by the third operation, the *Homalotatic pressure* found by the fourth operation, so as to leave an *Arrhopic system* of externally applied pressures; whose effects in producing internal stress and strain remain to be found.

The advantages of the method of decomposing the forces applied to an Elastic Solid arise from the following circumstances :—

First. It is impossible to determine the effect of any system of forces applied to an elastic solid, unless such system be self-balanced.

Secondly. It is, if not impossible, extremely difficult to determine directly the effect upon an elastic solid of any self-balanced system of forces which are not all parallel, unless they correspond to an uniform state of stress.

Thirdly. The difficulties of any problem respecting the stress of an elastic solid are often much increased if the applied pressures are not parallel to an axis of co-ordinates chosen with reference to the figure of the solid.

It is, therefore, desirable that all those pressures whose effects are not capable of being expressed by a state of stress uniform at every molecule of the solid (like that due to Homalotatic Pressure) should be reduced to a system or systems whose components parallel to any axis whatsoever are self-balanced, and may therefore have their effects separately computed—that is, to an Arrhopic system, or systems; and this is what is accomplished by the processes above described. To complete the solution, therefore, of the problem of the internal equilibrium of any elastic solid near the earth's surface, it is only necessary to find the separate effects of three *Residual* Arrhopic self-balanced systems of parallel pressures, parallel respectively to such axes as the figure of the body may render most convenient.

(8.) *Cases in which the Distribution of Internal Stress is Independent of the Co-efficients of Elasticity of the Solid.*

THEOREM.—When the molecular displacements are expressed by algebraical functions of the co-ordinates not exceeding the second degree, and the stresses (consequently) by constants and linear functions of the co-ordinates, the distribution of internal stress is independent of the co-efficients of elasticity of the solid.

Demonstration.—The cases in which the distribution of internal stress is independent of the co-efficients of elasticity, are those in which the number of arbitrary constants in the functions expressing the internal stresses is not greater than the number of arbitrary constants in the functions expressing the molecular displacements; so that, consequently, the internal stresses can be determined from the external forces alone.

The internal stress at any point is expressed by six components, linear

functions of the first differential co-efficients of the molecular displacements, which last are three in number.

When these are expressed by transcendental or other irrational functions, the former number of constants is double of the latter; hence this class of cases is excluded.

When the molecular displacements are expressed by three homogeneous rational and integral functions of the three co-ordinates of the $\underline{n^{th}}$ degree, the number of arbitrary constants contained in them is $\frac{3}{2}(n+1)(n+2)$.

In the same case, the component stresses are expressed by six rational and integral homogeneous functions of the degree $\underline{n}-1$; so that in them the number of arbitrary constants is $\frac{6}{2}n(\underline{n}+1)$.

Hence the ratio borne by the number of arbitrary constants in the expressions for stresses to the corresponding number in the expressions for molecular displacements, is

$$\frac{2n}{n+2}.$$

This ratio is less than, equal to, or greater than unity, according as $\underline{n}$ is less than, equal to, or greater than 2; therefore the distribution of stress is independent of the co-efficients of elasticity for molecular displacements expressed by rational functions not exceeding the second degree, and stresses expressed by constants and by linear functions of the co-ordinates. *Q. E. D.*

As n increases indefinitely, the above-mentioned ratio approximates to 2, being its value for irrational functions.

(9.) *The Classes of External Pressures* which produce stresses answering the preceding description are the following:—

Homalotatic Pressures, for which the stresses are expressed by constants, and *Antibarytic*, *Homalocamptic*, and *Homalostrephic Pressures*, for which the stresses are expressed by linear functions.

It has already been seen, that for the systems of pressures designated as *Homalotatic* and *Antibarytic*, the internal stresses are determined independently of the co-efficients of elasticity of the body, being in the former case uniform, and in the latter consisting in a vertical normal stress, which is a linear function of the vertical ordinate from the horizontal plane of the body's centre of gravity. The consideration of these two systems of stresses forms part of the solution of every problem concerning the equilibrium of an elastic solid.

DEFINITIONS.—*Homalocamptic Pressures* (or pressures of Uniform Bending).—A system of external pressures corresponding to a system of normal internal stresses uniform in direction, whose intensity is a linear function of an

ordinate perpendicular to that direction, measured from a surface passing through the body's centre of gravity. That is to say, the centre of gravity being the origin, let O $\underline{x}$ be any direction in which there is a normal stress N_x, let $\underline{b}$, $\underline{c}$, be two constants, and let

$$N_x = by + cz \quad . \quad . \quad . \quad (11),$$

which fulfils of itself the differential equations (7) of internal equilibrium. Then by the equations (4)—

$$\left.\begin{aligned} P &= n_x N_x = n_x (by' + cz') \quad . \quad . \quad (12), \\ Q &= 0 \; ; \; R = 0 \; ; \end{aligned}\right.$$

will represent a system of Homalocamptic Pressures.

Homalostrephic Pressures, or Pressures of Uniform Twisting.—A system of pressures corresponding to a system of tangential internal stresses uniform as to the pair of internal directions in which they act, and whose intensity is a linear function of an ordinate perpendicular to those directions, and measured from a plane passing through the body's centre of gravity; that is to say, for example, let

$$T_x = a x \quad . \quad . \quad . \quad (13),$$

which fulfils of itself the equations (7). Then by the equations (4)—

$$\left.\begin{aligned} P = 0 \; ; \; Q &= n_z T_x = a x' n_z \; ; \\ R &= n_y T_x \; = a x' n_y \end{aligned}\right\} \quad . \quad (14).$$

A system of Homalostrephic Pressures is equivalent to a pair of systems of Homalocamptic Pressures, making angles of 45° with the directions of the Homalostrephic Pressures. For let Oy_1, Oz_1, be a pair of axes in the plane yz, inclined at 45° to y and z, so that $+y$ lies between $+y_1$ and z_1. Then is T_x equivalent to a pair of normal stresses,

$$\left.\begin{aligned} N_{y1} &= -T_x = -a x \\ N_{z1} &= +T_x = +a x \; . \end{aligned}\right.$$

Prop. V.—Theorem. *Every Homalocamptic System of Pressures is Arrhopic.*

For the following are the Rhopimetric co-efficients derived from equation (12)—

$$B = 0 \; ; \; C = 0 \; ; \; D = 0 \; ;$$

$$\left.\begin{aligned} A &= \iint P x' \, d^2s = b \iint x' y' \, . \, dy \, dz + c \iint z' x' \, . \, dy \, dz \; ; \\ E &= \iint P z' \, d^2s = b \iint y' z' \, . \, dy \, dz + c \iint z'^2 \; . \, dy \, dz \; ; \\ F &= \iint P y' \, d^2s = b \iint y'^2 \; . \, dy \, dz + c \iint y' z \, . \, dy \, dz \; ; \end{aligned}\right.$$

($dy \, dz$ being as usual considered as $+^{ve}$ or $-^{ve}$, according to the sign of n_x).

Now each term of A is null, because the origin is the centre of gravity of the body; and each term of E and F is null, because for each positive element $dy\,dz$ of the projection of the body's surface there is an equal negative element.

$$\therefore A = 0;\ E = 0;\ F = 0;$$

and the system of pressures is Arrhopic. *Q. E. D.*

Corollary 1. Every Homalostrephic System of Pressures is Arrhopic.

Corollary 2. The subtraction from any Arrhopic system of pressures, of a Homalocamptic or Homalostrephic system, leaves an Arrhopic residual system.

(10.) EXAMPLE.—*Homalocamptic Pressures, Uniform Bending Stress in a Prism.*—The consideration of Homalocamptic and Homalostrephic Pressures does not, like that of Homalotatic and Antibarytic Pressures, form an essential part of the solution of every problem of the internal equilibrium of an Elastic Solid; but is to be employed only when it evidently tends to simplify the problem.

The most generally useful example of a single system of Homalocamptic Pressures is the following :—

Let the axis of x be that of a prismatic pillar, traversing its centre of gravity. Then for the ends of the prism respectively,

$$n_x = \pm 1;\ n_y = 0;\ n_z = 0;$$

and for the sides, $n_x = 0$. Let $bz = cy$ be the equation of any plane passing through the centre of the prism, and let each element of the ends of the prism be acted on by normal pressures, proportional to the distance from that plane, tensile towards $+y$, and compressive towards $-y$. Then for

$$\left.\begin{aligned} &n_x = \pm 1,\ P = \pm(by + cz);\ Q = 0;\ R = 0; \\ \text{and for}\quad &n_x = 0,\ P = 0,\ Q = 0,\ R = 0; \end{aligned}\right\} \quad . \quad (15),$$

and the internal stresses are

$$N_x = by + cz;\ N_y = N_z = T_x = T_y = T_z = 0 \quad . \quad (16).$$

When a system of normal pressures is distributed *in any manner* on the two ends of a prism, the system of Homalocamptic Pressures which approximates most nearly to the actual system is found by computing the moments of the pressures on *one end* relatively to the planes xy and zx, viz.,

$$\iint Pz\,dy\,dz \quad \text{and} \quad -\iint Py\,.\,dy\,dz,$$

and make

$$b = \frac{\iint \mathrm{P}z \,.\, dy\, dz}{\iint z^2 \,.\, dy\, dz}\,;\quad c = \frac{\iint \mathrm{P}y \,.\, dy\, dz}{\iint y^2 \,.\, dy\, dz} \qquad . \qquad . \qquad (17).$$

The denominators of these expressions are the geometrical factors of the moments of inertia of the cross-section of the prism round y and z respectively. It is obviously immaterial which end of the prism is chosen for the computations.

(11.) *Example of Homalostrephic Pressures; Uniform Twisting Stress in an Elliptic Cylinder.*

Let O x be the longitudinal axis of an Elliptic Cylinder, O y and O z parallel to its greatest and least diameters, and let $2p$ and $2q$ be those diameters. Then for the ends of the cylinder,

$$\underline{n}_x = \pm 1\,;\ \underline{n}_y = 0\,;\ \underline{n}_z = 0\,;$$

and for the elliptic surface

$$n_x = 0\,;\ n_y = \frac{ym}{p^2}\,;\ n_z = \frac{zm}{q^2}\,;$$

when

$$m = \frac{1}{\sqrt{\frac{y^2}{p^4} + \frac{z^2}{q^4}}}\,;$$

Let there be two Homalostrephic systems of Tangential Stresses, thus represented

$$\mathrm{T}_y = by\,;\ \mathrm{T}_z = cz\ .$$

Then the external pressures constituting a pair of Homalostrephic systems combined, will be as follows:—

On the ends,

$$\text{for } \underline{n}_x = \pm 1\,;\ \mathrm{P} = 0\,;\ \mathrm{Q} = \pm cz\,;\ \mathrm{R} = \pm by,$$

on the elliptic surface

$$\mathrm{P} = n_y \mathrm{T}_z + n_z \mathrm{T}_y = myz\,.\,\left\{\frac{c}{p^2} + \frac{b}{q^2}\right\}\,;\ \mathrm{Q} = 0\,;\ \mathrm{R} = 0\ .$$

Now let the external pressures be subject to the condition that the pressure on the elliptic surface shall be everywhere null; then we must have

$$\frac{c}{p^2} + \frac{b}{q^2} = 0\ .$$

Consequently, let

$$bp^2 = -cq^2 = a\ ,$$

and we shall have for the internal stresses

$$T_y = +\frac{ay}{p^2}\ ;\ T_z = -\frac{az}{q^2} \qquad . \qquad . \qquad (18),$$

and for the external pressures at the ends of the cylinders, which are wholly tangential;

$$\text{for } \underline{n_x} = \pm 1\ ;\ Q = \mp\frac{az}{q^2}\ ;\ R = \pm\frac{ay}{p^2} \qquad . \qquad . \qquad (19).$$

The resultant tangential pressure at any point (y, z) of one end of the cylinder, or of one of its sections,

$$\left.\begin{aligned} &\sqrt{Q^2 + R^2} = \frac{a}{m}\ ;\ \text{being pro.} \\ &\text{and its direction-cosines are} \\ &\frac{Q}{\sqrt{Q^2 + R^2}} = \mp\frac{zm}{q^2}\ ;\ \frac{R}{\sqrt{Q^2 + R^2}} = \pm\frac{ym}{q^2} \end{aligned}\right\} \qquad . \qquad (20),$$

showing it to be a tangent to an ellipse similar and concentric to the outline of the end of the cylinder, and proportional to the diameter of that ellipse to which it is parallel.

The total *moment of torsion* M, that is, the moment about O x of the forces applied to *one end* of the cylinder, is as follows:—

$$\iint (Ry - Qz)\, dy\, dz = a \iint \left(\frac{y^2}{p^2} + \frac{z^2}{q^2}\right) dy\, dz\ ,$$

which, because

$$\frac{y^2}{p^2} + \frac{z^2}{q^2} = 1\ ,$$

becomes

$$M = a \times \text{area of elliptic base} = \pi apq \qquad . \qquad (21),$$

which equation serves to determine the constant a when the moment of torsion is given, viz.,

$$a = \frac{M}{\pi pq}\ .$$

The tangential stresses at the extremities of the greatest and least diameters of the ends are inversely as those diameters, viz.,

$$T_y = \frac{a}{p} = \frac{M}{\pi p^2 q}\ ;\ T_z = -\frac{a}{q} = -\frac{M}{\pi pq^2} \qquad . \qquad . \qquad (22).$$

These results agree with those obtained by Cauchy, but have the peculiarity of being arrived at independently of the co-efficient of elasticity of the substance.

XXIII.—*On the Geometrical Mean Distance of Two Figures on a Plane.*

By Prof. J. Clerk Maxwell, F.R.S.

(Received January 5th ; read January 15th, 1872.)

There are several problems of great practical importance in electro-magnetic measurements, in which the value of a quantity has to be calculated by taking the sum of the logarithms of the distances of a system of parallel wires from a given point. The calculation is in some respects analogous to that in which we find the potential at a point due to a given system of equal particles, by adding the reciprocals of the distances of the particles from the given point. There is this difference, however, that whereas the reciprocal of a line is completely defined when we know the unit of length, the logarithm of a line has no meaning till we know not only the unit of length, but the modulus of the system logarithms.

In both cases, however, an additional clearness may be given to the statement of the result by dividing, by the number of wires in the first case, and by the number of particles in the second. The result in the first case is the logarithm of a distance, and in the second it is the reciprocal of a distance ; and in both cases this distance is such that, if the whole system were concentrated at this distance from the given point, it would produce the same potential as it actually does.

In the first case, since the logarithm of the resultant distance is the arithmetical mean of the logarithms of the distances of the various components of the system, we may call the resultant distance the geometrical mean distance of the system from the given point.

In the second case, since the reciprocal of the resultant distance is the arithmetical mean of the reciprocals of the distances of the particles, we may call the resultant distance the harmonic mean distance of the system from the given point.

The practical use of these mean distances may be compared with that of several artificial lines and distances which are known in Dynamics as the radius of gyration, the length of the equivalent simple pendulum, and so on. The result of a process of integration is recorded, and presented to us in a form which we cannot misunderstand, and which we may substitute in those elementary formulæ which apply to the case of single particles. If we have any doubts about the value of the numerical co-efficients, we may test the expression

for the mean distance by taking the point at a great distance from the system, in which case the mean distance must approximate to the distance of the centre of gravity.

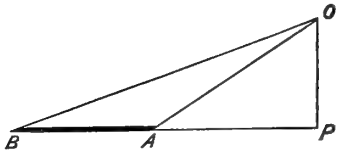
Thus it is well known that the harmonic mean distance of two spheres, each of which is external to the other, is the distance between their centres, and that the harmonic mean distance of any figure from a thin shell which completely encloses it is equal to the radius of the shell.

I shall not discuss the harmonic mean distance, because the calculations which lead to it are well known, and because we can do very well without it. I shall, however, give a few examples of the geometric mean distance, in order to show its use in electro-magnetic calculations, some of which seem to me to be rendered both easier to follow and more secure against error by a free use of this imaginary line.

If the co-ordinates of a point in the first of two plane figures be x and y, and those of a point in the second ξ and η, and if r denote the distance between these points, then R, the geometrical mean distance of the two figures, is defined by the equation

$$\log \mathrm{R} \cdot \iiiint dx\, dy\, d\xi\, d\eta = \iiiint \log r\, dx\, dy\, d\xi\, d\eta \ .$$

The following are some examples of the results of this calculation :—



(1.) Let AB be a uniform line, and O a point not in the line, and let OP be the perpendicular from O on the line AB, produced if necessary, then if R is the geometric mean distance of O from the line AB,

$$\mathrm{AB} \cdot (\log \mathrm{R} + 1) = \mathrm{PB} \cdot \log \mathrm{OB} - \mathrm{PA} \log \mathrm{OA} + \mathrm{OP} \cdot \mathrm{A\hat{O}B} \ .$$

(2.) The geometrical mean distance of P, a point in the line itself, from AB is found from the equation

$$\mathrm{AB}\,(\log \mathrm{R} + 1) = \mathrm{PB} \log \mathrm{PB} - \mathrm{PA} \log \mathrm{PA} \ .$$

When P lies between A and B, PA must be taken negative, but in taking the logarithm of PA we regard PA as a positive numerical quantity.

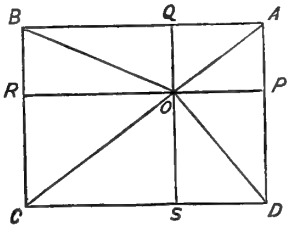
(3.) If R is the geometric mean distance between two finite lines AB and CD, lying in the same straight line,

$$\mathrm{AB} \cdot \mathrm{CD}\,(2 \log \mathrm{R} + 3) = \mathrm{AD}^2 \log \mathrm{AD} + \mathrm{BC}^2 \log \mathrm{BC} - \mathrm{AC}^2 \log \mathrm{AC} - \mathrm{BD}^2 \log \mathrm{BD} \ .$$

(4.) If AB coincides with CD, we find for the geometric mean distance of all the points of AB from each other

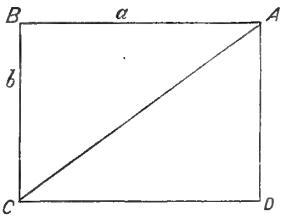
$$R = AB\, e^{-\frac{3}{2}} .$$

(5.) If R is the geometric mean distance of the rectangle ABCD from the point O in its plane, and POR and QOS are parallel to the sides of the rectangle through O,



$$\begin{aligned} ABCD\,(2\log R + 3) = {} & 2OP\,.\,OQ\log OA + 2OQ\,.\,OR\log OB \\ & + 2OR\,.\,OS\,\log OC + 2OS\,.\,OP\log OD \\ & + OP^2\,.\,D\hat{O}A \qquad + OQ^2\,.\,A\hat{O}B \\ & + OR^2\,.\,B\hat{O}C \qquad + OS^2\,.\,COD \end{aligned}$$

(6.) If R is the geometric mean of the distances of all the points of the rectangle ABCD from each other,



$$\log R = \log AC - \frac{1}{6}\frac{AB^2}{BC^2}\log\frac{AC}{AB} - \frac{1}{6}\frac{BC^2}{AB^2}\log\frac{AC}{BC} + \frac{2}{3}\frac{AB}{BC}\,B\hat{A}C + \frac{2}{3}\frac{BC}{AB}\,A\hat{C}B - \frac{25}{12} .$$

When the rectangle is a square, whose side $= a$,

$$\begin{aligned} \log R &= \log a + \frac{1}{3}\log 2 + \frac{\pi}{3} - \frac{25}{12} \\ &= \log a - 0{\cdot}8050866 \\ R &= 0{\cdot}44705\, a . \end{aligned}$$

(7.) The geometric mean distance of a circular line of radius a, from a point in its plane at a distance r from the centre, is r if the point be without the circle, and a if the point be within the circle.

(8.) The geometric mean distance of any figure from a circle which completely encloses it is equal to the radius of the circle. The geometric mean distance of any figure from the annular space between two concentric circles, both of which completely enclose it, is R, where

$$(a_1^2 - a_2^2)\left(\log R + \frac{1}{2}\right) = a_1^2\log a_1 - a_2^2\log a_2 ,$$

a_1 being the radius of the outer circle, and a_2 that of the inner. The geometric mean distance of any figure from a circle or an annular space between two con-

centric circles, the figure being completely external to the outer circle, is the geometric mean distance of the figure from the centre of the circle.

(9.) The geometric mean distance of all the points of the annular space between two concentric circles from each other is R, where

$$(a_1^2 - a_2^2)^2 (\log \mathrm{R} - \log a_1) = \frac{1}{4}(3a_2^2 - a_1^2)(a_1^2 - a_2^2) - a_2^4 \log \frac{a_1}{a_2} \ .$$

When a_2, the radius of the inner circle, vanishes, we find

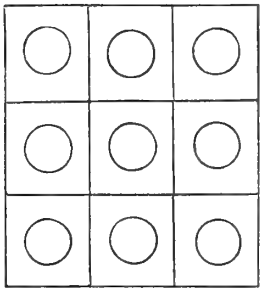
$$\mathrm{R} = a\, e^{-\frac{1}{4}} \ .$$

When a_2, the radius of the inner circle, becomes nearly equal to a_1, that of the outer circle,

$$\mathrm{R} = a_1 \ .$$

As an example of the application of this method, let us take the case of a coil of wire, in which the wires are arranged so that the transverse section of the coil exhibits the sections of the wires arranged in square order, the distance between two consecutive wires being D, and the diameter of each wire *d*.

Let the whole section of the coil be of dimensions which are small compared with the radius of curvature of the wires, and let the geometrical mean distance of the section from itself be R.



Let it be required to find the co-efficient of induction of this coil on itself, the number of windings being *n*.

1*st*, If we begin by supposing that the wires fill up the whole section of the coil, without any interval of insulating matter, then if M is the co-efficient of induction of a linear circuit of the same shape as the coil on a similar parallel circuit at a distance R, the co-efficient of induction of the coil on itself will be

$$n^2 \mathrm{M} \ .$$

2*d*, The current, however, is not uniformly distributed over the section. It is confined to the wires. Now the co-efficient self-induction of a unit of length of a conductor is

$$\mathrm{C} - 2 \log \mathrm{R} \ ,$$

where C is a constant depending on the form of the axis of the conductor, and R is the mean geometric distance of the section from itself.

Now for a square of side D,

$$\log \mathrm{R}_1 = \log \mathrm{D} + \frac{1}{3} \log 2 + \frac{\pi}{3} - \frac{25}{12} \ ,$$

and for a circle of diameter d

$$\log R_2 = \log d - \log 2 - \frac{1}{4} .$$

Hence

$$\log \frac{R_1}{R_2} = \log \frac{D}{d} + \frac{4}{3}\log 2 + \frac{\pi}{3} - \frac{11}{6} ,$$

and the co-efficient of self-induction of the cylindric wire exceeds that of the square wire by

$$2\{\log \frac{D}{d} + 0{\cdot}1380606\}$$

per unit of length.

3*d*, We must also compare the mutual induction between the cylindric wire and the other cylindric wires next it with that between the square wire and the neighbouring square wires. The geometric mean distance of two squares side by side is to the distance of their centres of gravity as 0·99401 is to unity.

The geometric mean distance of two squares placed corner to corner is to the distance between their centres of gravity as 1·0011 is to unity.

Hence the correction for the eight wires nearest to the wire considered is

$$-2 \times (0{\cdot}01971) .$$

The correction for the wires at a greater distance is less than one-thousandth per unit of length.

The total self-induction of the coil is therefore

$$n^2 M + 2l\{\log \frac{D}{d} + 0{\cdot}11835\} ,$$

where n is the number of windings, and l the length of wire.

For a circular coil of radius $= a$,

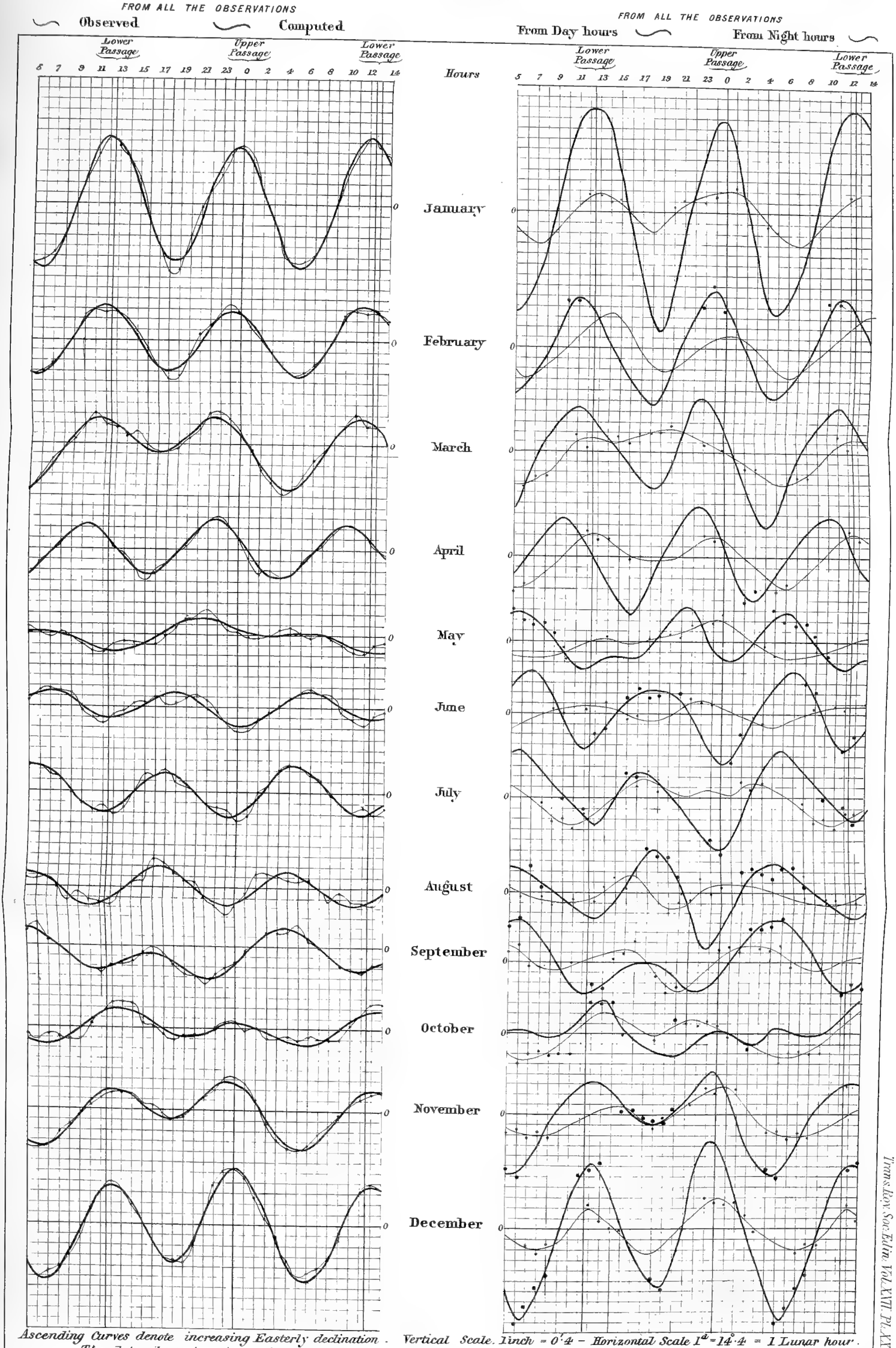
$$M = 4\pi a(\log 8a - \log R - 2) ,$$

where R is the geometrical mean distance of the section of the coil from itself.

NATURAL HISTORY

MEAN LUNAR DIURNAL VARIATION OF MAGNETIC DECLINATION FOR EACH MONTH AT TREVANDRUM, 1854–1864.

BY J. A. BROUN.



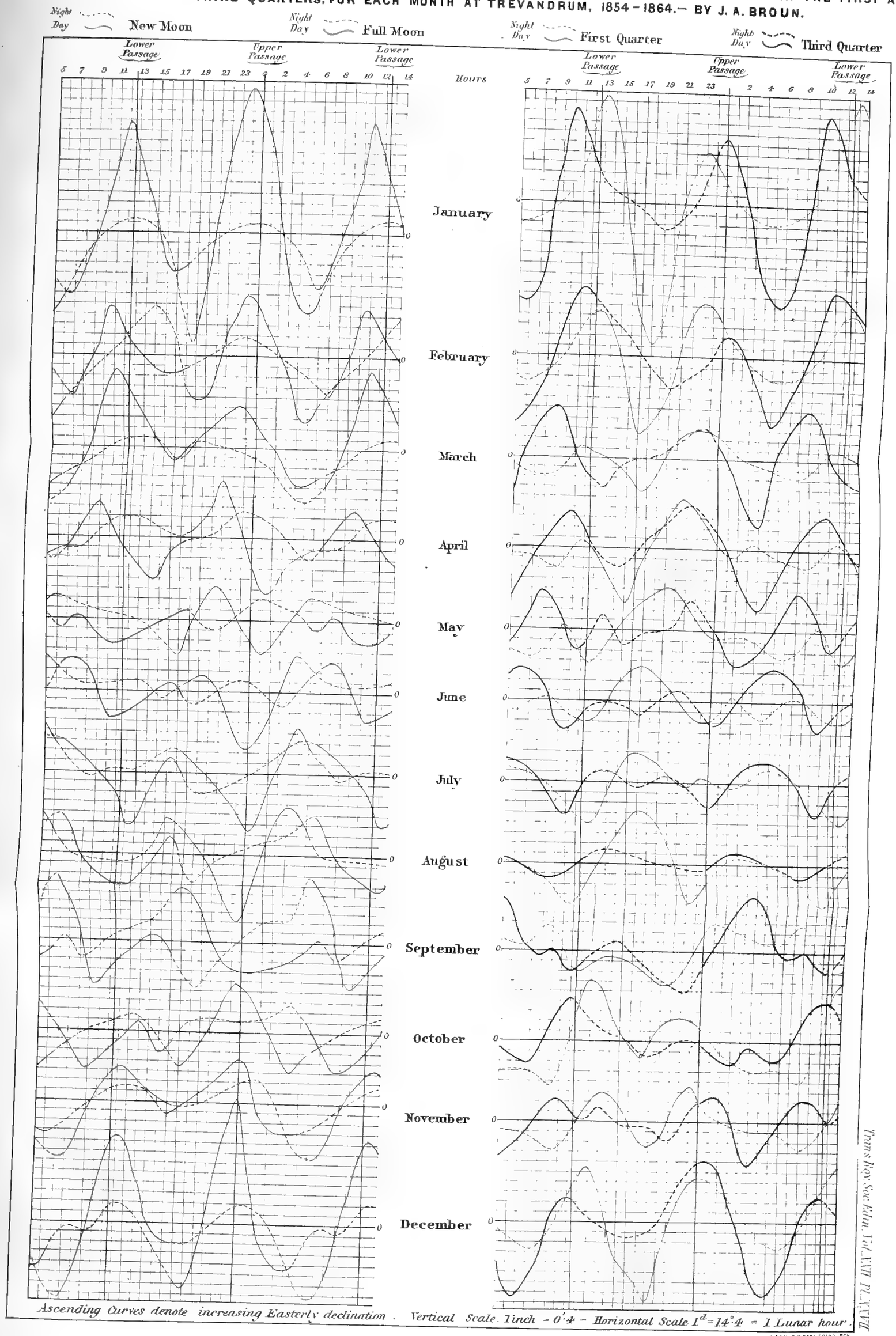
Ascending Curves denote increasing Easterly declination. Vertical Scale. 1 inch = 0'·4 – Horizontal Scale 1d = 14°·4 = 1 Lunar hour.
The dots show the observed points where the curves have been drawn between them, and not through them.

Trans. Roy. Soc. Edin. Vol. XVII. Pl. XXVI.

W. & A. K. Johnston Edinburgh

BRITISH
NATURAL HISTORY

MEAN LUNAR DIURNAL VARIATION OF MAGNETIC DECLINATION FOR THE MOON NEW, FULL AND AT THE FIRST AND THIRD QUARTERS, FOR EACH MONTH AT TREVANDRUM, 1854–1864.— BY J. A. BROUN.



Ascending Curves denote increasing Easterly declination. Vertical Scale. 1 inch = 0'·4 – Horizontal Scale 1^{d} = 14°·4 = 1 Lunar hour.

Trans Roy. Soc. Edin. Vol. XXII Pl. XXVII

W & A K JOHNSTON EDINBURGH

Moons Age 0d
1d
2d
3d
4d
5d
6d
7d
L.P.
U.P.
Each day is the mean from 3 days preceding and 3 days following
1st From single days
2nd From single days
h 19·06
h 17·04
h 16·07
h 15·05
h 14·05
h 13·10
h 12·05
True hour angle of the Moon at the sunrise observation
N.B. The single days here are not like those above of the moon's age The first day corresponds more nearly to the moon ½ to ¾ day old and the last to about 7½ days old
Sunrise
Sunset
Vertical Scale. 1 inch = 0·8 – Horizontal Scale 1 division = 2h = 28°·8 = 2 Lunar days. Ascending Curves denote increasing Easterly declination.

XXIV.—*On the Lunar Diurnal Variation of Magnetic Declination at Trevandrum, near the Magnetic Equator, deduced from Observations made in the Observatory of His Highness the Maharajah of Travancore, G.C.S.I.*

By J. A. Broun, F.R.S. (Plates XXVI.–XXVIII.)

(Read 6th May 1872.)

1. The lunar diurnal variation of magnetic declination as first discovered by Kreil, depended on too few observations to be free from the errors introduced by irregular disturbing causes. The independent discovery of the lunar action on the magnetic needle made afterwards by myself, was liable to the same criticism; but the agreement of the results obtained, both for the magnetic declination and the horizontal force, was sufficiently great to give a considerable value to the conclusion, that the magnetic needle obeys a diurnal law, depending on the moon's hour angle, both as to its direction and the force with which it is directed. This conclusion was farther confirmed in the discussion first made by myself, for the lunar diurnal variation of the vertical magnetic force, which gave, within an hour, the same epochs of maxima and minima as those obtained previously by me for the horizontal component.*

The results obtained afterwards from longer series of observations,† while less affected by the irregularities due to disturbances, still showed variations of so small a range, that the fact of the existence of a lunar diurnal variation was not accepted by all men of science without reserve. Whatever doubt may have existed before has been dissipated, I have every reason to believe, by the results communicated in a paper to the Royal Society of Edinburgh in 1867,‡ where variations were shown due to the lunar action, which equalled those produced by the sun.

2. This action of the moon is not constant; it not only varies with the period of the year, but it varies also for the same month in different years; so that, in some seasons, the variation is still so small, as to require the combination of large masses of observations to eliminate the effects of irregular causes, in the determinations relating to the laws of variation under different circumstances.

3. Though observations made in different parts of the world, both in the northern and southern hemispheres, seemed to prove the existence of a law of

* Trans. Royal Soc. Edin., vol. xvi. p. 143, § 19.

† The most important of these have been discussed by General Sir E. Sabine.

‡ Trans., vol. xxiv. p. 669.

lunar diurnal variation, no conclusions had been drawn either as to the way in which the law varied in passing from one hemisphere to another, or as to the way in which it might change near the equator with the position of the sun or moon in declination. As nothing is known as to the mode in which the sun and moon produce these variations, nothing could certainly be predicted *a priori* as to the change of the law under the circumstances just mentioned.

4. The first result obtained from a discussion of observations made during the five years 1854 to 1858 at Trevandrum, was that the law of lunar diurnal variation for the group of months about January was the inverse of that for the months about July.* This fact, which held also for the solar diurnal variation, appeared to relate both variations to the position of the earth in its orbit, rather than to the passage of the sun from one hemisphere to the other. The similarity in the change of the law of lunar and solar diurnal variation for the sun north and south of the equator, led also to the conclusion that the mean lunar diurnal movement, like the mean solar diurnal movement, should be in opposite directions in the high latitudes of the two hemispheres: the facts have since then been found to be in accordance with this conclusion.†

5. The next question of importance was, whether the moon's passage from one hemisphere to the other would produce any marked change in the law of variation, or in its amount. The discussion of five years' observations seemed to show a considerable difference in the relative magnitude of the maximum and minimum, not only with the moon farthest north and south, but also with the position of the moon on the equator, according as she was moving towards the north or towards the south.

6. As the action of the moon on the needle may vary from different causes, it becomes necessary, to be sure in obtaining the results for any given argument, that we have got rid of the effects dependent on other arguments.

If we assume, in the first instance, that the solar diurnal variation is the same for each day throughout a month, and that a similar supposition holds for the moon; then, as in a month, which is nearly equal to a lunation, the moon will have been on all the twenty-four meridians at each of the solar hours, the mean disturbing action of the moon will have been the same at each of the solar hours, and the mean position of the needle for each solar hour, as derived from a month's observations, will be equally affected or unaffected by the lunar action.‡ A similar conclusion may be arrived at relatively to the mean position of the needle for the moon on different meridians: thus, if all the observations made during a lunation for the moon on the principal meridian be summed

* Proceedings of the Royal Society of London, vol. x. p. 475. 1861.

† Proc. Roy. Soc. Lond., vol. xvi. p. 59.

‡ Hence the mean solar diurnal variation sought, in any case, from fewer than a month's observations will be more or less in error, according as the lunar action (and the change of its law during the lunation) is more or less considerable

together, all for the moon on the meridian of one hour, and so on, and the means be taken, we see in each case that the sun will have been on all the meridians for each of these hour angles of the moon; and the means thus obtained will be equally affected by the solar action. The process is the same as for the solar diurnal variation.

If, however, the suppositions made are inaccurate, and the solar diurnal action is not constant during a month, the hourly means for the lunar diurnal variation will not be equally affected by the solar action. A similar conclusion holds for the solar diurnal variation, if the law of lunar diurnal variation is not constant throughout the month.

7. Besides this possible source of error, there is at least another which depends upon unknown causes, the effects of which have been named disturbances. In order to determine the extent of the disturbance at different hours, each observed position is compared with the monthly mean for the corresponding hour, and the means of the differences thus obtained give comparative measures of the disturbance or displacement of the needle at the different hours.

The discussions for this purpose have shown that the disturbance, though irregular in action, yet on the whole obeys a solar diurnal law, so that in the mean of a sufficient number of observations the disturbing action, like the usual solar action, will be eliminated, and this the more easily when the days of greatest disturbance are omitted.

8. As it is thought probable that the larger disturbances, at least, are independent of the lunar action, it has been sought to avoid the irregularities which they introduce when limited series of observations are discussed. Three methods have been employed for this end. By one all the observations differing from the corresponding hourly mean by a certain arbitrary limit have been suppressed, the hourly means for the month have been recomputed from the remaining observations, and the differences taken as if the suppressed observations had not existed.* By the second (employed by me in the first discussions for the lunar diurnal variation from the Makerstoun observations for 1844–1845), the observations exceeding a certain arbitrary limit were considered disturbed, and quantities were substituted for them, derived from preceding and succeeding observations, which were within the limit. In the third method, which was employed by me in the first discussion of the Trevandrum observations;† *all the observations* in days which were considered days of marked disturbance were omitted.‡

* I have touched on the objections to this method in a note which appeared in the Proceedings of the Royal Society, of London, vol x. p. 479. The Astronomer Royal (*Trans. Roy. Soc. Lond.*, vol. cliii. p. 617), and Dr Lloyd (*Dublin Mag. Observ.*, vol. i. p. 91, foot note) have also both objected to this process.

† Proc. Roy. Soc. Lond., vol. x. p. 481.

‡ The test for determining whether a day is one of marked disturbance has been obtained in different manners. I believe that the most certain test would be one depending on the value of the

There are objections to all these methods, in as far as the rules for rejection or substitution are empirical, and have really no scientific basis. The objections to the second method are probably the least important, since the interpolated values depend on those preceding and succeeding; and in this respect the operation is somewhat similar to that, where the observed quantities are deduced from photographic registration, by drawing a line among the points.

9. It has been stated that the third method, that of rejecting all the observations in days considered disturbed, was that employed in the first discussion of the Trevandrum observations. It was, however, found, after the discussion had been performed, that nearly all the days rejected *were simply days much affected by the lunar action;* the lunar diurnal variations probably amounting on some occasions to upwards of five minutes, while the mean solar diurnal variation did not exceed the half of that amount. In consequence of this discovery, the discussion was made finally including all the observations.*

10. The differences, obtained by deducting the hourly means from the observations for the corresponding hours, which are equally positive and negative for a given solar hour during a month, are still affected by the whole lunar action; so that they will in a given day be positive or negative, more or less positive, or less or more negative, according as the lunar action tends to increase or diminish the deviation of the needle. These differences which are required in the discussion for the solar disturbance serve also for the determination of the lunar diurnal variation, as well as the observed values from which they are derived, with the advantage, that having the mean solar diurnal variation already deducted, they can be combined more readily with reference to any given argument.

11. The supposition that the law of solar action is constant throughout a month can be considered only approximately true: near the magnetic equator, especially in the months near the equinoxes, the law varies rapidly. To avoid as far as possible any error due to this cause in the discussion of the Trevandrum observations, the mean solar diurnal variation was calculated corresponding to each week in each year in the following manner:—The hourly means were obtained from the observations in the 1st, 2d, 3d, and 4th weeks of the year 1854; from those in the 2d, 3d, 4th, and 5th weeks; from those in the 3d to 6th weeks; and so on to the end of the series in 1865. The means obtained from the first series of four weeks were then combined with those from the second series, and the means derived from this combination were considered to represent the mean

mean difference obtained by comparing each hourly observation with that immediately following it; the characteristic mark of what is termed a disturbance being the irregular movement of the needle.

* With a single exception (in about 80,000 observations) in which the mean of the preceding and succeeding observations was substituted.

solar diurnal variation in the middle (or third) week. These hourly means were then compared with the observations at the corresponding hours in the third week, and the differences obtained. The hourly means from the second and third sets of four weeks served in a similar manner for the observations during the fourth week. In a like way the differences were found for all the observations throughout the series.

12. It is still supposed that the hourly means obtained from the observations in four successive weeks represent the solar diurnal variation unaffected by any inequality of the lunar action. The following discussions make it probable that the mean action of the moon at each solar hour during a lunation is constant, or so nearly so, that any error due to this cause may be neglected.

Mean Lunar Diurnal Variation for each Month in the Year.

13. As the diurnal variation of the magnetic needle produced by the moon has generally been found small, it has been usual to combine the results from all the lunations throughout the year, in order to destroy the effects of disturbing causes which still remain, even after a considerable portion of the observations has been rejected for this object. Although this combination may give approximations to a general law in high latitudes, it cannot be expected to do so near the equator; the first discussion of the Trevandrum observations having shown the law to be inverted in the course of six months; the combination for that locality of all the observations made during the year, gave a result which is purely arithmetical, without any representative in fact. As nothing was known as to the mode in which the law changed from one form to another, it was necessary to determine it for each month in the year. This has now been done by the discussion of nearly eighty thousand hourly observations made during the eleven years, 1854 to 1864. The resulting values, which will be found in the first volume of the Trevandrum Observations, with a more detailed account of the reductions, are projected in curves in the first half of Plate XXVI.

14. As these curves present some slight irregularities, it is believed that an elimination of the effects of disturbance, as far as they are independent of the lunar action, will be best made in calculating the most probable variation from the deduced quantities by the formula of sines,

$$y = a_1 \cos \theta + b_1 \sin \theta + a_2 \cos 2\theta + b_2 \sin 2\theta.$$

The following are the resulting equations for each month, together with the probable error of each result as derived from the four terms only:

Jan.	$y =$	$-$	0·0233	cos θ	$-$	0·0143	sin θ	$+$	0·2264	cos 2θ	$-$	0·0442	sin 2θ	Prob. error 0·018
Feb.		$-$	·0126	„	$-$	·0084	„	$+$	·1155	„	$-$	·0463	„	„ ·011
Mar.		$-$	·0290	„	$-$	·0633	„	$+$	·0676	„	$-$	·0788	„	„ ·014
April		$+$	·0026	„	$-$	·0122	„	$+$	·0386	„	$-$	·0900	„	„ ·009
May		$+$	·0406	„	$-$	·0134	„	$-$	·0193	„	$-$	·0203	„	„ ·013
June		$-$	·0045	„	$-$	·0142	„	$-$	·0532	„	$-$	·0082	„	„ ·013
July		$-$	·0128	„	$+$	·0318	„	$-$	·0827	„	$+$	·0350	„	„ ·012
Aug.		$-$	·0001	„	$-$	·0089	„	$-$	·0566	„	$+$	·0378	„	„ ·017
Sept.		$+$	·0104	„	$+$	·0566	„	$-$	·0358	„	$+$	·0511	„	„ ·010
Oct.		$-$	·0246	„	$-$	·0206	„	$+$	·0415	„	$+$	·0197	„	„ ·015
Nov.		$+$	·0158	„	$-$	·0611	„	$+$	·0904	„	$-$	·0008	„	„ ·014
Dec.		$+$	·0355	„	$-$	·0324	„	$+$	·1740	„	$+$	·0303	„	„ ·012

The following are the equivalent equations for the diurnal and semi-diurnal periods, or,

$$y = a'_1 \sin(\theta + c_1) + a'_2 \sin(2\theta + c_2).$$

Jan.	$y =$	0·0273	sin	(θ +	238°	24′)	+	0·2307	sin	(2θ +	101°	3′)
Feb.	$y =$	·0151	sin	(θ +	236	14)	+	·1244	sin	(2θ +	111	50)
Mar.	$y =$	·0697	sin	(θ +	204	35)	+	·1038	sin	(2θ +	139	32)
April	$y =$	·0126	sin	(θ +	167	45)	+	·0980	sin	(2θ +	156	47)
May	$y =$	·0428	sin	(θ +	108	12)	+	·0280	sin	(2θ +	223	30)
June	$y =$	·0149	sin	(θ +	197	28)	+	·0538	sin	(2θ +	261	12)
July	$y =$	·0343	sin	(θ +	338	3)	+	·0898	sin	(2θ +	292	55)
Aug.	$y =$	·0089	sin	(θ +	180	3)	+	·0681	sin	(2θ +	303	45)
Sept.	$y =$	·0575	sin	(θ +	10	25)	+	·0624	sin	(2θ +	324	58)
Oct.	$y =$	·0321	sin	(θ +	230	4)	+	·0459	sin	(2θ +	64	38)
Nov.	$y =$	·0631	sin	(θ +	165	32)	+	·0904	sin	(2θ +	90	30)
Dec.	$y =$	·0481	sin	(θ +	132	18)	+	·1766	sin	(2θ +	80	7)

15. The conclusions from the observed and calculated variations are as follow (see Plate XXVI.) :—

1*st*, The mean lunar diurnal variation consists of a double maximum and minimum of easterly declination in each month of the year.

2*d*, In December and January, the maxima occur near the times of the moon's upper and lower passages of the meridian; while in June, they occur six hours later, the minima then occurring near the time of the two passages of the meridian.

3*d*, The change of the law for December and January to that for June and July, does not occur as in the case of the solar diurnal variation, by leaps in the course of single months (those of March and October), but more or less gradually for different maxima and minima.

16. But the change of hours for the maxima and minima will be better seen in the following table, where the epochs derived from the computed variations,* as well as those deduced from the observed quantities are given.

* The epochs for the diurnal and semi-diurnal periods are obtained directly from the values of c_1 and c_2 in the preceding series of formulæ; those for both terms are obtained from the formulæ by the equation

$$\alpha = \frac{dy}{d\theta}\,\frac{1}{y},$$

TABLE I.—*Epochs of Maxima and Minima of easterly Declination in the Lunar Diurnal Variation for each Month, as derived from the calculated Variations and by estimation from the Projection of the observed Means.*

Month.	Diurnal term.		Semi-diurnal term.				Both terms.							
							Calculated.				Estimated from observations.			
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.
Jan.	14 6	2 6	11 38	17 38	23 38	5 38	11 42	17 44	23 34	5 33	11 40	17 44	23 55	5 8
Feb.	14 15	2 15	11 16	17 16	23 16	5 16	11 17	17 21	23 11	5 12	11 14	17 35	23 5	5 8
Mar.	16 22	4 22	10 21	16 21	22 21	4 21	11 0	16 21	21 43	4 21	10 55	16 50	21 45	4 0
April	18 49	6 49	9 46	15 46	21 46	3 46	10 0	15 41	21 41	3 52	10 5	15 22	21 50	3 50
May	22 48	10 48	7 25	13 25	19 25	1 25	6 0	12 48	20 26	2 58	5 15?	11 15?	20 40	2 0
June	9 8	21 8	6 23	12 23	18 23	0 23	6 30	12 0	18 11	0 30	6 15	11 20	18 35	0 30
July	6 52	18 52	5 8	11 18	17 18	23 18	5 25	11 33	17 0	22 56	4 50	12 15	16 20	0 0
Aug.	18 0	6 0	4 52	10 52	16 52	22 52	4 50	10 45	16 55	23 0	4 20	12 30	16 40	23 0
Sept.	5 18	17 18	4 10	10 10	16 10	22 10	4 23	11 7	15 50	21 23	4 50	11 30	16 10	20 55
Oct.	14 40	2 40	0 51	6 51	12 51	18 51	0 29	6 8	13 17	19 30	23 40	6 40	13 30	18 15
Nov.	19 6	7 6	23 59	5 59	11 59	17 59	23 22	6 8	12 40	17 47	23 30	5 30	13 25	18 30
Dec.	21 11	9 11	0 20	6 20	12 20	18 20	0 9	6 30	12 32	18 9	23 45	6 25	12 25	18 35

17. No conclusion of any value can be drawn from the epochs for the diurnal term; the irregularity shown in the hours for the different months for this term, probably depends on causes which will be noticed hereafter (35). The semi-diurnal term which gives the largest oscillation, excepting in May and October, shows a rather regular change of the epochs from one month to the other, the most marked exception being from September to October, when the change is 3 h. 19 m. It is, however, the whole variations that we have at present especially to consider, and for these the calculated epochs are the most certain.

18. If we commence with the maximum, which occurs in January near the moon's upper passage (23 h. 34 m.), and follow the change of hour for this maximum till June, when it happens six hours before the upper passage, and thence to December, when it is near the lower passage (thus going through twelve hours in the twelve months), we find that the greatest leaps occur from May to June ($2\frac{1}{4}$ h.), and from September to October ($2\frac{1}{2}$ h.) In the months of March and April this maximum occurs about 2 h. 20 m. before the upper passage, and in September 3 h. 50 m. after the lower passage.

On the other hand, the maximum which happens near the inferior passage (11 h. 42 m.) in January, changes suddenly four hours from April to May, and from September to October.

The two minima change hour with considerable regularity, with one marked exception, which occurs again from September to October.

On the whole, we can conclude that though the maxima occur near the upper and lower passages in December, and at six hours after these epochs in June, that they happen nearly midway between the two in April and September.

where α is the correction to an estimated epoch of the maximum or minimum. See footnote to a paper on the "Horizontal Form of the Earth's Magnetism," Trans. Roy. Soc. Edin., vol. xxii. p. 529.

19. *4th*, While the lunar diurnal variation changes the hours of maxima and minima more gradually than the solar diurnal variation, it also makes the greatest changes at different times. Thus the solar diurnal variation changes completely during the month of March, or from February to April, while the lunar diurnal variation makes the greatest change from April to May. The second change which happens for the sun between September and November occurs earlier, or between September and October for the moon.

Range of the Mean Lunar Diurnal Variation.

20. When we examine the range of the variation in the different months of the year, we find :—

5th, That the range is greatest in January, and least in May and October; the arc, including the mean diurnal variation for January, from eleven years' observation, being nearly $0'{\cdot}5$ $(= 30'')$, while in May the range was $0'{\cdot}18$ $(= 10''{\cdot}8)$, in October $0'{\cdot}14$ $(= 8''{\cdot}4)$, and in July $0'{\cdot}26$ $(= 15''{\cdot}6)$.

21. It has been shown in a paper already cited,* that the lunar diurnal variation is sometimes as large as the solar diurnal variation, amounting in December and January sometimes to upwards of five minutes of arc (5′), which, allowing for the greater inclination of the needle (or the smaller horizontal force), would be equivalent to about 12′ in England. But this great oscillation, which sometimes occurs within 24 hours, is subjected to different laws of variation which, when the mean for a week only is taken, diminish the range so much that, for example, in the lunation 16th December 1858 to 12th January 1859,† the greatest range for a week's observations is reduced to $2'{\cdot}7$, while the range for the whole lunations is less than half that amount. When the mean diurnal variation is derived from all the lunations occurring principally in January during eleven years, the range is still further reduced to $0'{\cdot}5$ nearly. This is partly due to the fact that the lunar action does not appear to be equally powerful in the same month in different years.‡

22. *6th*, The ranges of the mean lunar and solar diurnal variations thus obey different laws relatively to the epoch of the year; the range for the former in January being nearly double that in any month from May to September, while the range of the latter (the solar diurnal variation) in January is little more than half that for August.

23. Although it would be difficult to prove from the ranges of the solar diurnal variations observed at different stations on the earth's surface (even

* Trans. Roy. Soc. Edin., vol. xxiv. p. 673.

† See the projections for this lunation, Plate XLIII., Trans. Roy. Soc. Edin., vol. xxii.

‡ It is also partially due to the mode of combination—a lunation being considered *in* January, if fifteen days were in that month, the other fourteen being in February or December, for which months the range is considerably less than in January, and the maxima and minima occur at different times.

when reduced to the same directive force) that the solar action is greater in December than in June (for the whole earth), yet it seems not improbable that the great lunar action observed at Trevandrum during the months of December and January is connected with the greater proximity of the earth and moon to the sun at that time of the year.

Changes of the Lunar Diurnal Variation with the Moon's Declination.

24. The next question of importance which presented itself was that relating to the moon's passage from one hemisphere to the other. The first investigations in answer to this question seemed to show, as already mentioned, that the law of lunar diurnal variation not only varied with the moon farthest north and farthest south, but even with the position on the equator according as she was moving towards the north or towards the south. There was nothing contrary to our knowledge in this result, the solar diurnal law for March not resembling in any way that for September or October. This discussion, which had been made for the two groups of months, April to September, and October to March, from the observations in 1854 to 1858, was extended to the eleven years' observations, and to each month of the year. The results obtained were not consistent. The change of law which appeared due to the moon's passage from the southern to the northern hemisphere in January was not the same as that shown for the same movement of the moon in February, and resembled still less that which occurred in March. The discussions (each requiring the combinations of nearly 80,000 quantities) made in a similar manner with reference to the moon's phase and distance from the earth threw no light on this discrepancy.

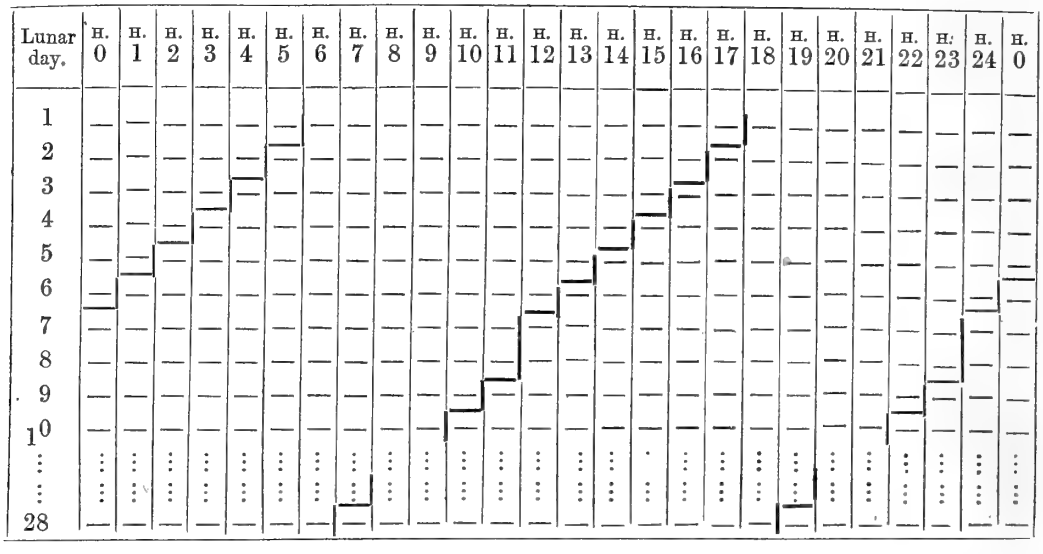
25. In another discussion with reference to the law of disturbance as related to the moon's hour angle,* it occurred to me that it would be desirable to compare the result which might be deduced from the night hours, when the solar disturbance is least at Trevandrum, with that derived from the day hours, when the solar disturbance is greatest. The conclusions arrived at from this discussion, together with a consideration of the curves representing the apparent variation of the law of lunar diurnal variation with the moon's declination, induced me to employ a similar analysis for the lunar diurnal variation. As the conclusions from this investigation are most important, it is necessary to describe the process made use of. The apparent effect of the moon's change of declination will be considered thereafter.

Change of the Law of Lunar Diurnal Variation with the Day and Night.

26. Having subducted the solar diurnal variation from the hourly observa-

* See Proc. Roy. Soc. Lond., 20th June 1861. The law of lunar disturbance is that relating to the greater or lesser *irregularity* of the position of the needle in the diurnal variation for the *moon* on the different meridians.

tions in the different weeks, the differences due to the lunar action (and irregular causes) were arranged in columns under the lunar hours to which they respectively belong, as in the following scheme, where the short lines indicate the + or − differences.*



The first difference under 0 h. with which the lunation begins is that derived from the observation made half an hour after noon (the lunation always beginning with the new moon), and corresponding to the moon on the meridian. The difference under 6 h. in the first lunar day corresponds to after sunset, while that under 17 h. corresponds to before sunrise. Thus the differences before and after sunset are separated by a light zigzag line, while those before and after sunrise have a thicker zigzag between them.

It is obvious that, if each horizontal line represents the lunar diurnal variation during a lunar day, and if this variation obeys the same law, or nearly the same law, throughout a lunation, it does not matter how we obtain the means from the vertical columns of differences; and the means obtained from the night hours (those within the zigzag lines commencing with 6 h. to 17 h.) should give the same result as those to be obtained from the day hours. If, however, the law varies with any argument, such as the moon's declination or phase, this will be proved by a comparison of the results for different lunations in different months of the year.

* It will be seen in the scheme that the lunar day has been considered equal to 25 hours (it is equal to 24 h. 50 m. nearly), and consequently the lunar hour angle is equal to only 14°·4. Also 0 h. is repeated in the last column. This was always done in order to find the correction due to changes of mean declination, which caused the variations to increase or diminish from the 1st to the following 0 h., especially in means derived from limited series of observations. It was found ultimately that it would be preferable to repeat 1 h., and perhaps even 2 h. in order to obtain this correction with more accuracy. Other details as to the precautions taken in these discussions will be found in the first volume of Trevandrum Observations.

Thus, if the scheme just given represents a lunation in December, the moon will be farthest south in the first days of the lunation, and the night hours will correspond to the lunar hour angles of 6 h. to 17 h. ; while for a lunation in June, the moon will be farthest north when the night hours correspond to the same lunar hours ; in the intermediate months, the position of the moon in declination will be different at the commencement of each lunation, and the night hours will thus correspond to the same lunar hours for all the different positions of the moon.

27. It has been, however, supposed that each horizontal line represents the lunar diurnal variation in the same way ; but we know that the mean position of the magnetic needle varies from day to day. A separate investigation has shown that the change of the daily mean is, if not wholly independent of the varying positions of the moon, so nearly so that its effect on this discussion may be neglected, and the other changes may be considered as irregular variations, the effects of which will be eliminated in the discussion of a sufficiently large number of observations.*

If, now, we obtain the means of the vertical columns for the night hours, these means will correspond to all the positions of the moon (in declination, &c.), a similar remark holds for the means obtained from the day hours. The sums having been taken for the night hours in the lunations, the whole or greater part of which occurred in January in each of the eleven years, these were combined, and the means taken ; a similar operation was performed for the day hours ; and in each case this was done for each of the twelve months. The conclusions from this discussion are as follows. See second half of Plate XXVI., where the derived means are projected.

28. *7th,* The action of the moon on the declination needle is, in every month of the year, greater during the day than during the night ; the range of the oscillation in January and June, being between three and four times greater during the day than during the night, the ratio being less in the intermediate months.

The following are the ranges, and the areas of the curves (from observation and computation by formulæ similar to those given (14)) for day and night, with their ratios for each month of the year :—

		Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Range observed,	Day,	0′·85	0′·47	0′·49	0′·41	0′·24	0′·36	0′·40	0′·39	0′·31	0′·23	0′·41	0′·69
	Night,	0′·24	0′·26	0′·23	0′·22	0′·14	0′·11	0′·22	0′·18	0′·21	0′·21	0′·20	0′·23
Ratio,	$\frac{\text{Day,}}{\text{Night,}}$	3·6	1·8	2·1	1·8	1·6	3·2	1·9	2·1	1·5	1·1	2·1	3·0

* Had the method here considered, or an idea of any probable result to be derived from it, presented itself at first, differences, independent of the irregularities of the daily means, would have been obtained by reducing each of the daily means to the monthly mean, so that the sums of the plus and minus differences in each lunar day would have been equal to zero.

		Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Area observed,	Day,	6′·20	3′·05	2′·96	2′·59	1′·66	2′·25	2′·18	2′·23	1′·94	1′·01	2′·34	4′·47
	Night,	1′·39	1′·45	1′·60	1′·17	0′·85	0′·60	0′·98	0′·85	1′·07	1′·23	1′·26	1′·44
Ratio,	$\frac{\text{Day,}}{\text{Night,}}$	4·5	2·1	1·9	2·2	2·0	3·8	2·2	2·6	1·8	0·8	1·9	3·1
Ranges calculated,	Day,	0′·85	0′·38	0′·43	0′·35	0′·20	0′·31	0′·35	0′·27	0′·29	0′·17	0′·37	0′·64
	Night,	0′·20	0′·22	0′·19	0′·18	0′·13	0′·07	0′·14	0′·09	0′·16	0′·16	0′·20	0′·20
Ratio,	$\frac{\text{Day,}}{\text{Night,}}$	4·2	1·7	2·2	1·9	1·5	4·3	2·4	3·0	1·8	1·1	1·8	3·1
Area computed,	Day,	6′·29	3′·06	2′·95	2′·60	1′·33	2′·22	2′·16	2′·08	1′·86	0′·98	2′·37	4′·39
	Night,	1′·25	1′·41	1′·56	1′·20	0′·80	0′·49	0′·97	0′·61	0′·99	1′·12	1′·13	1′·39
Ratio,	$\frac{\text{Day,}}{\text{Night,}}$	5·0	2·2	1·9	2·2	1·7	4·5	2·2	3·4	1·9	0·9	2·1	3·2

The computed ratios are probably the nearest to the truth, as they are free from the irregularities due to accidental disturbances. From the ratio for the areas of the computed curves (for which the sums of the co-ordinates are employed) the day is to the night as 5 to 1 in January, and as $4\frac{1}{2}$ to 1 in June. The ratio is least in May and October, the two months in which the curve becomes inverted, the day and night areas for the latter month being nearly equal.

29. This is a fact which is wholly independent of the question as to its cause, whether connected with the varying positions of the moon or not. The law of variation, however, for the day hours in each month of the year is so consistent, that it becomes exceedingly probable that the change of law previously found as apparently connected with the moon's varying declination is chiefly, if not altogether due to this cause (the different action in sunlight and in the shade of night). The law deduced from the night hours shows a variation of such small range, that it is comparatively more affected by the irregularities due to change of the daily mean declination and other causes.

30. If the law of lunar diurnal variation really depends on the moon's position in declination, then the method just described will give results, in which some of the diurnal curves for any month will be made up of the parts of the curves belonging to the day hours for the moon's different positions, and others to the parts belonging to the night hours. We can, perhaps, best judge to what extent the moon's declination (or longitude) is connected with these results by an examination of the projected curves derived from the discussion for the moon's declination.*

Thus, to begin with January, the curve for the week with the moon farthest north shows the maximum of easterly declination, which happens near the

* *Postscript.*—When this was written it was intended to give the projected curves for the different positions of the moon in declination; this the Postscript (43) and the Plate (XXVII.), with curves for

moon's lower passage, to be much greater than the other near the upper passage; while for the moon farthest south in January it is just the reverse. Now this difference is connected also with the fact, that in each of these cases the greatest maximum happened in the day hours—that is to say, when the moon is farthest north in January the lower passage occurs in the day-time; and when farthest south in January, the upper passage occurred in the day-time.

A similar difference is shown for the weeks in January, when the moon was near the equator, moving north and moving south; when moving north, the most marked minimum occurred about six hours *before* the upper passage, and when moving south, the marked minimum happened six hours *after* the upper passage; both of these epochs corresponded to the day hours.

31. Had, however, the change in the moon's declination been a cause of these differences in the values of the extreme elongations, we should expect the same cause to produce similar effects in other months. If in January, the moon being farthest north caused the maximum at the lower passage to be the greatest, a similar result might be expected in February and March, for which months the law of the mean diurnal variation is nearly the same. This is not the case. In February and March the greatest maximum occurs near the lower passage, not when the moon is farthest north, but when on the equator, moving south.*

In June, when the moon was farthest north,† the variation may be said to have been zero near the lower passage, instead of, as in January, being the most important for this position of the moon. Also, when the moon was farthest south in June, the movement near the upper passage is very small,‡ which is just the reverse of the fact for the same position of the moon in January.

32. An examination of the results for each month of the year, in the same way, leads to the conclusion that the variable magnitude of the maxima and minima depends chiefly, if not wholly, on the hours of the day corresponding to the hour angles of the moon for which there is a maximum or minimum of easterly declination. This conclusion will be evident on examining the projected

the times of the moon's phases, render unnecessary; for the conclusions here drawn the curves for the phases may be consulted, approximately, as follows :—

In January, for moon farthest north, see curve for full moon.
„ „ south, „ new moon.
„ „ on equator moving north, see curve for 1st quarter.
„ „ „ south, „ 3d quarter.
In February, on equator moving south, see 3d quarter.
In March, „ „ see full moon.

* See curves for third quarter in February, and for full moon in March.

† See curve for new moon in June.

‡ See curve for full moon in June, Plate XXVII.

curves, where the parts derived chiefly from day-hours are distinguished from those from the night-hours.*

33. It was still a question, whether there might not be some difference in the lunar action in the forenoon and in the afternoon, and in the first and second halves of the night. Though the number of observations to be discussed did not seem great enough, in comparison with the irregularities to be neutralised, to allow a quite satisfactory reply to this question, the discussion was, however, performed for the four parts of the day.

The result for January, the month of greatest lunar diurnal variation, and consequently, that for which any difference should be most easily perceived, was found well marked. In January the forenoon hours showed the greatest minimum six hours *before* the upper passage, while the afternoon hours gave the greatest minimum six hours *after* the upper passage; and the range of the variation, in each case, was nearly six times greater than that derived from the night hours. But though differences are found in the results from forenoon and afternoon hours in the other months of the year, they are never so well marked nor neither do they resemble those for January. It is probable, then, that this difference is due to some other cause, or some additional cause which is felt only in that part of the earth's orbit.

The differences in the results for the two halves of the night are too small and irregular to found any conclusion upon them.

34. All the day hours together give variations for each month of the year resembling those already considered as derived from all the observations day and night, consisting of a double maximum and minimum in each month of the year, with varying epochs.

35. The variations derived from all the night hours do not appear to change epochs from month to month, as in those obtained from the day hours; the law of variation appears on the whole to be nearly constant throughout the year; that is to say, a maximum of easterly declination occurs in all the months of the year near the times of the upper and lower passages of the meridian.

36. The mean lunar diurnal variations, as derived from all the observations made throughout the year at different stations on the earth's surface, have presented the common feature of the greatest deviation of the needle towards the west in the northern hemisphere, and towards the east in the southern hemi-

* It will be obvious that this separation cannot be perfect, since, for example, in the vertical summation of the first seven horizontal lines in the scheme (26), when the difference of day and night hours is disregarded (as in the discussions for the moon's position), the mean for the lunar hour 3 would be obtained from three observations made during the day and four during the night. In the projected results, six hours on each side of the mean midnight point are marked as night hours; that point would correspond to the lunar hour $8\frac{1}{2}$ in the means for the first week in the scheme. In this way, however, the extremes of parts marked as night hours are still affected by the greater action of the day. An examination of Plate XLIII., Trans. Roy. Soc. Edin., vol. xxiv. (differences under solar hours), will show the small lunar effect during the night hour throughout a lunation.

sphere, within an hour and a half of the moon's passages of the meridian. We see from the present discussion how these means include different causes of variation, producing absolute inversion of the laws (at least during the day) near the magnetic equator, and that in such positions the mean for the year may not represent the fact at any period; also for different latitudes, it is probable that the law will vary during the year with the different lengths of the day and night.

37. It has long been known that the solar diurnal variation was greatest during the day; we now find this is true, also, for the lunar diurnal variation. We might suppose that there is a greater amount of the magnetic ether heaped up over the face of the earth next the sun than on the other side in the earth's shadow, and that the moon's action upon this ether is thus greatest where the greatest disturbance can be produced. In whatever direction the hypothetical electrical currents proceed, their intensity (or quantity) diminishes within the earth's shadow, and is it not improbable that the result now found for the variation of the easterly magnetic force will be found true also for the northerly and vertical forces.*

Diurnal Variation with reference to the Moon in the Half Orbits farthest from and nearest to the Earth.

38. The only other discussion in connection with the lunar diurnal variation which it seems to me of sufficient importance to give here, is that connected with the moon's distance from the earth. For this question the discussion was divided into two parts: First, for the months October to April; and second, for the group May to September; in each case the law of diurnal variation within the group is sufficiently constant to allow a conclusion from the mean variations.

The equations of sines computed from the means are as follows:—

October to April.

Apogee $\left\{\begin{array}{l} y = +0'{\cdot}0014\cos\theta - 0'{\cdot}0249\sin\theta + 0'{\cdot}1049\cos 2\theta - 0'{\cdot}0061\sin 2\theta \\ \quad = +0'{\cdot}0249\sin(\theta + 176^\circ\,52') + 0'{\cdot}1050\sin(2\theta + 93^\circ\,19') \end{array}\right\}$ Prob. error = 0′·005.

Perigee $\left\{\begin{array}{l} y = -0'{\cdot}0024\cos\theta - 0'{\cdot}0316\sin\theta + 0'{\cdot}1114\cos 2\theta - 0'{\cdot}0494\sin 2\theta \\ \quad = +0'{\cdot}0317\sin(\theta + 182^\circ\,21') + 0'{\cdot}1218\sin(2\theta + 113^\circ\,54') \end{array}\right\}$,, = 0′·013.

May to September.

Apogee $\left\{\begin{array}{l} y = -0'{\cdot}0098\cos\theta + 0'{\cdot}0118\sin\theta - 0'{\cdot}0446\cos 2\theta + 0'{\cdot}0046\sin 2\theta \\ \quad = +0'{\cdot}0153\sin(\theta + 320^\circ\,4') + 0'{\cdot}0448\sin(2\theta + 275^\circ\,57') \end{array}\right\}$,, = 0′·013.

Perigee $\left\{\begin{array}{l} y = +0'{\cdot}0118\cos\theta + 0'{\cdot}0006\sin\theta - 0'{\cdot}0578\cos 2\theta + 0'{\cdot}0236\sin 2\theta \\ \quad = +0'{\cdot}0118\sin(\theta + 86^\circ\,53') + 0'{\cdot}0624\sin(2\theta + 292^\circ\,13') \end{array}\right\}$,, − 0′·008.

* The calculations are being made with reference to these components of force.

From the means of the observations, and the quantities computed by the preceding equations, we obtain the following results :—

39. In the group October to April, the areas of the curves representing the observed and computed variations are in the ratios—

For Apogee : for Perigee : : 1 : 1·18 by observation ;
„ „ : : 1 : 1·15 by computation.

While for the group May to September the ratios are—

For Apogee : for Perigee : : 1 : 1·31 by observation ;
„ „ : : 1 : 1·38 by computation.

The ratios of the ranges of the two oscillations (from the observed quantities) are approximately

October to April, . . A : P = 1 : 1·20
May to September, . . A : P = 1 : 1·24

The total ranges of the oscillations by computation are in the ratios

October to April, . . A : P = 1 : 1·18
May to September, . . A : P = 1 : 1·26

40. The ratios appear greatest for the mean curves representing the group of months May to September, but an examination of the ratios of the areas of the curves for the separate months (which vary considerably, and from other causes than that of distance), shows that this difference is accidental. On taking the ratios of the areas of the observed curves for each month, and the means of these ratios for the six months October to March, and April to September, we obtain—

October to March, . . A : P = 1 : 1·25
April to September, . . A : P = 1 : 1·23

This agreement of the ratios is probably accidental, since when the means of the ratios for the six months January to June, and July to December, are taken, they are found as 1 : 1·14, and as 1 : 1·34 respectively. But in whatever way we obtain the ratios, the mean for the year is always nearly the same, or

A : P = 1 : 1·24 nearly,

which is probably not far from the truth.

41. The ratio of the moon's mean distance from the earth in the half orbit about apogee is to that in the half orbit about perigee nearly as 1·07 is to 1 ; as the cube of 1·07 = 1·23 nearly, we see that the mean ranges of the curves, as well as the mean areas, for the two distances are in the approximate ratios of the inverse cubes of the moon's distance from the earth, as in the theory of the tides.

42. The regular double maximum and minimum shown in all the mean results obtained for the lunar diurnal variation of the magnetic elements has given the idea that the variations are due to the action of an attractive force; any such idea will now require some modification such as that suggested (37) in order to satisfy the facts of this paper.*

POSTSCRIPT.†

43. In the preceding paper, no allusion has been made to the results when related to the moon's phase; these phases coinciding nearly in each month with one of the four positions of the moon in declination, for which the curves had been projected, it did not seem necessary to give the curves for the phase also. It has been pointed out (foot note to 32) that the day and night hours overlap each other when the means for several successive days are taken, and therefore the separation of the part of the curve derived from day hours, from that derived from the night hours, is not perfectly definite.

This, however, is the case in these combinations, not only from the mode of combining several successive days, but also because, for example, in the month of January, the moon does not pass the meridian at the same hour for the day she is farthest north in different years, the difference amounting to upwards of three hours in the course of the eleven years. It seemed desirable, then, to avoid this latter complication, in order to show more distinctly the difference betwixt the movements during the day and during the night hours. This was best done in the combinations for the moon's phase, since the moon is on the meridian at noon nearly on the day of new moon, and at midnight nearly on the day of full moon; the only indefiniteness remaining is that common to both combinations, depending on the overlapping in the means of successive days already noticed.

After communicating the results of the preceding paper to the Royal Society, I projected the curves for each month corresponding to the new moon, first quarter, full moon, and third quarter. That is to say, the means derived from

* The mean diurnal variations of the atmospheric pressure due to the sun and moon, show similar regular double maxima and minima. The consideration of a mass of observations made by me in India at different heights, induced me several years ago (*Phil. Mag.*, August 1858) to suggest an electro-magnetical attraction as a cause of these variations (and I found an analogical phenomenon in the action of the sun on the gases of comets). The atmosphere having acquired a certain polarity, would by this attraction assume ellipsoidal forms with the longer axis directed towards the attracting luminaries (or making nearly constant angles with these directions), thus producing waves or currents as a given meridian turns round under axes of different lengths. I have in consequence of this idea sought to find some connection between the laws of terrestrial magnetism and those of atmospheric pressure, but hitherto without any conclusive result. The difference of the lunar action on the magnetic needle during the day and during the night, suggested the examination of the lunar diurnal variation of atmospheric pressure for a like difference; but the result of this investigation was negative, no difference being perceptible; the lunar diurnal variation in January and June was shown equally well by the observations during the night and by those during the day.

† Added by permission of the Council, June 27th 1872.

combining the lunar diurnal variations for each of these phases with those for three days before and three days after them.

44. The curves for the new moon have been projected in thin lines, and those for full moon in thick lines on the same zero line (see Plate XXVII.); similarly for the curves for the first and third quarters in thin and thick lines respectively. In each case the night part of the curve is distinguished from the day part, the former being a dotted, the latter a continuous, line.

45. The principal conclusions to be drawn from these curves are the following:—

1*st*, The great difference of the amount of movement during the day and during the night is shown distinctly in each case.

2*d*, If we consider, in the first instance, the curves for the new moon, we find in the months of January to May, that the north end of the needle changes its direction of motion, and begins to move rapidly eastward at *sunrise* (almost exactly at sunrise). This holds true till new moon in May; but in June the direction is completely reversed, the north end of the needle turning westwards shortly after sunrise; this continues in July, August, and September, but at the new moon in October the reversal again occurs more distinctly than in May: the needle now moves rapidly eastward after sunrise till June again.

3*rd*, The same statement holds for full moon, only that the movements in May and October are combinations of those for the preceding and succeeding months. I have no doubt that the change would be shown equally well and equally rapidly from one direction to the other, if the full and new moon always happened at exactly the same points of the earth's orbit, but these results are derived from combinations of observation for full moons occurring in the beginning and in the end of May and October, and therefore partaking partly of the character due to the preceding and following months.

4*th*, When we examine the curves for the first and third quarters, which are projected together, we find for both quite similar results to the preceding, only that the motion after sunrise is towards the west in January and towards the east in June.

46. Thus, if sunrise happens when the moon is near the meridian of 18 h. (that is, at new moon, the sun rising always near 18 h. at Trevandrum), or near the meridian of 6 h. (full moon), the needle then turns from its previous direction and moves rapidly (relatively speaking) eastwards in the months from October to May, and westwards from May to October. When the moon is on the meridian of 12 h., or 0 h. at sunrise, the directions of movement are the reverse of the preceding. That is to say, whether a maximum or minimum of easterly declination should happen at sunrise, the movement following takes place comparatively rapidly.

47. If we had found previously that a minimum or a maximum always hap-

pened when the moon was on one of the meridians of 0 h., 6 h., 12 h., and 18 h., there would have been nothing remarkable in this result, it would have agreed with previous ideas of the mean law of lunar diurnal variation; but this is not the case, the maxima and minima occurring at hour angles differing from the above by three hours in some months, and changing hour with more or less regularity from month to month. It could scarcely, therefore, be supposed to be a coincidence dependent on the true law of variation.

48. At least two questions present themselves in reference to this result: First, How this constancy of maxima and minima for fixed hour angles of the moon can agree with the fact of the change of hour shown (18) in the means for each month? We find an explanation of the apparent contradiction when we examine the curves for the phases, and consider the maxima and minima which do not happen at sunrise. Thus, the curve for new moon in the months of January to May shows that the principal maximum gradually shifts from an hour before the upper passage in January, to 3 h. before it in April and May. Similarly the passage of the minimum (in the same curves) for the moon on the meridian of 5 h. in January, to on the meridian of 0 h., though not equally regularly, is clearly shown. The change for the corresponding minimum in the third quarter happening more gradually from $5\frac{1}{2}$ h. in January to 0 h. in July.

49. The next question has reference to the mode in which the moon acts on the needle, on days intermediate betwixt two of the quarters; when, for example, she is on the meridian of 17 h., 16 h., 15 h., at sunrise, how does the movement change from that shown in the thin curve in January (new moon), where the movement is rapidly eastward after sunrise to that shown in the thin curve for the first quarter, where the movement is rapidly westwards at the same solar hour? Does the epoch of maximum or minimum vary at all with sunrise, or does the coincidence seen in these curves hold only for the four positions of the moon to which the curves strictly belong?

50. In order to answer these questions, the consideration of one period of seven days will suffice; for this end twelve periods from new moon to the first quarter in the months of December and January, showing the greatest variations, were chosen. In each of these periods the sum was taken of the diurnal variations for each hour in the week, having new moon in the middle; the sums of the twelve sums thus found having been formed, the means (from seventy-two days) gave the mean variation corresponding to new moon. A similar calculation was made for the weeks having the moon, one, two, to seven days old in the middle. These means are projected, Plate XXVII.

51. It will be seen from these curves, that the sunrise seems to pass from the minimum near 18 h. to the maximum near 12 h., gradually and without having any marked influence on the epoch of minimum or maximum. These, however, are mean results, the curve for each day being derived from three days

before and three days after the day of the moon's age which it represents; and we have seen in the results of this paper, the danger of trusting in mean results where different laws may be in question, and one movement overlies another. It was sought then to determine with more distinctness the change of form from one day of the moon's age to another, and for this end, the lunar diurnal variation for the twelve single days of new moon was obtained, and that for each of the days for which the moon was, one, two, to seven days old.*

52. Though the number of days is scarcely sufficient to give means free from irregular disturbances, the results appear little affected by them; they are projected in the second line of curves, Plate XXVIII. Here we find that the minimum takes place at sunrise on the day of new moon, and next day; but when the moon is two days old, the minimum is half an hour after sunrise; on the third day it is an hour and a half after sunrise, and there appears an inflexion in the movement westward; on the fourth day the movement has already turned westward at sunrise, which is the case also on the fifth and sixth days; on the seventh day the movement westward begins only one and a half hour after sunrise.

53. These results appear then to show, that the turning point is, as it were, *attracted* by sunrise, and that the change from an easterly movement to a westerly movement at sunrise occurs within an interval of about two days.

54. So curious and unexpected a fact required a still more careful arrangement of the observations. On the days of new moon the observation near noon was always marked as 0 h. for the moon on the upper meridian; the next observation as the moon on the meridian of 1 h., and so on. As, however, the moon is not generally on the meridian at the time of the observation nearest noon at new moon, being sometimes half an hour before or after, an error of an hour occurred easily in the lunar hour corresponding to the following observations, so that in the combinations considered previously, the observation nearest sunrise was not always entered under the true lunar hour angle for a given day of the moon's age. Another method then was now employed, in order to avoid any error from this cause, and to insure that we have the exact effect produced at sunrise.

The observations nearest sunrise were made at 5 h. 58 m. A.M. in 1854 and 1855, and at 6 h. 28 m. A.M. in the following years.† In order to avoid any complication due to this difference of hour, the observations in 1854 and 1855 were not employed in the following combination. All the periods for which the new moon occurred, between the 10th December and the 20th January (the time

* As no observations were made on Sunday, there were twelve days' observations for new moon, and for the moon four and seven days old, eleven days for the moon six days old, ten days for the moon three days old, and only nine days for the moon one, two, and five days old.

† The time of sunrise varies at Trevandrum from 6 h. 8 m. M.T., on the 15th December, to 6 h. 20m. on the 15th January, a change due nearly altogether to the equation of time, the interval betwixt sunrise and true noon, being (refraction effect included) nearly 5 h. 48 m. during the whole month.

of the greatest lunar action), in the years from January 1856 to January 1865 were taken (with the exception of that having new moon the 16th December 1857, large disturbances having occurred on the 17th, 18th, and 19th).

The moon's hour angle corresponding to 6 h. 28 m. A.M. (mean time), was first computed to the nearest minute for each of the days from new moon to the first quarter, for each of the seventeen periods under discussion. The days on which the moon's hour angle was between 18·5 h. and 17·5 h. (at the above hour) were marked as 1d.; those in which the hour angles were betwixt 17·5 h. and 16·5 h. as 2d.; and so on to 12·5 h. and 11·5 h. The variations due to the lunar action were now arranged for 1d. under each other, according to the *solar* hours (beginning with 12 P.M.), so that all the observations made at the sunrise hour ($18\frac{1}{2}$) were under each other; the means of the vertical columns were then taken, and that at $18\frac{1}{2}$ h. corresponded to the mean of the calculated hour angles of the moon (= 18·06 h.) A similar calculation was made for each of the following days for which the moon's mean hour angle differed by an hour at $18\frac{1}{2}$ h. mean solar time. In this way any possible error is due to the variation of the moon's hour angle (differing on the average a quarter of an hour from the mean) corresponding to $18\frac{1}{2}$ h., and this error the previous results have shown to be of less importance than that due to overlapping of the observations before and after sunrise. The results of these combinations are given in Table II., and they are projected in the third line of curves of Plate XXVIII.,* the observation near sunrise ($6\frac{1}{2}$ A.M.) having an O round the point, and that near sunset a ×.

55. In this more accurate combination, we find that the needle's movement westwards on the first and second days ends at sunrise; on the third day, the greater part of the movement westwards takes place after sunrise; on the fourth and following days, the movement westward *begins* at sunrise.

56. There is here, however, an additional fact of importance which presents itself on the fourth day: the movement is diminished so much that the variation has the appearance of being nearly obliterated. The moon's hour angle on this day at the sunrise observation is 15 h., and it seems as if, in this middle position, the needle were solicited by opposing forces.

57. The fact then is established, that the direction of the movement changes at or near sunrise, and that near the time when the needle emerges from the earth's shadow into sunlight the moon's action is reversed. This sudden reversal bears some resemblance to that shown in the curves from April to May, or May to June; for example, in the curves for the first quarter (Plate XXVII.)

* It must be remembered that these curves cannot be compared with those preceding them, day by day; 1d. (under 0d. in the plate) does not correspond to new moon (but to half a day or more after it), and there are only six days here included between the day for the moon on the meridian near noon, and the moon on the meridian at 6 h. P.M., whereas seven days were included by the other method.

for April and May. In the former month, the needle moves westwards, in the latter eastwards from the hour when the moon is on the inferior meridian (sunrise).

TABLE II.—*Mean Lunar Diurnal Variation on seven successive days, for the Moon on the Meridians of* 18 *h. to* 12 *h. at* 6½ A.M., *in January and December, derived from seventeen quarter Lunations,* 1856-65.*

Solar Hour, M. T.	1d.	2d.	3d.	4d.	5d.	6d.	7d.
12½ A.M.	− 0·05	− 0·13	+ 0·07	+ 0·06	− 0·16	− 0·11	− 0·05
1½ „	− 0·06	− 0·10	+ 0·13	+ 0·03	− 0·16	− 0·09	− 0·03
2½ „	− 0·07	− 0·07	+ 0·07	+ 0·03	− 0·07	− 0·00	+ 0·02
3½ „	− 0·10	− 0·14	+ 0·16	+ 0·04	+ 0·01	+ 0·09	− 0·05
4½ „	− 0·13	− 0·14	+ 0·08	+ 0·06	+ 0·05	+ 0·10	+ 0·16
5½ „	− 0·35	− 0·20	− 0·06	+ 0·04	+ 0·14	+ 0·20	+ 0·24
6½ „	− 0·69	− 0·55	− 0·24	+ 0·06	+ 0·40	+ 0·48	+ 0·54
7½ „	− 0·62	− 0·51	− 0·57	− 0·29	+ 0·22	+ 0·37	+ 0·62
8½ „	− 0·32	− 0·38	− 0·82	− 0·25	− 0·10	+ 0·16	+ 0·39
9½ „	+ 0·15	+ 0·08	− 0·72	− 0·18	− 0·48	− 0·35	− 0·06
10½ „	+ 0·48	+ 0·11	− 0·40	+ 0·13	− 0·91	− 0·58	− 0·64
11½ „	+ 0·43	+ 0·23	− 0·17	+ 0·26	− 0·66	− 0·52	− 0·79
0½ P.M.	+ 0·31	+ 0·40	+ 0·08	+ 0·25	− 0·31	− 0·36	− 0·61
1½ „	+ 0·11	+ 0·34	+ 0·46	+ 0·09	− 0·44	− 0·08	− 0·55
2½ „	− 0·20	+ 0·18	+ 0·45	+ 0·11	− 0·38	+ 0·36	− 0·35
3½ „	− 0·37	− 0·23	+ 0·29	+ 0·12	+ 0·22	+ 0·58	+ 0·07
4½ „	− 0·43	− 0·44	− 0·04	+ 0·12	+ 0·47	+ 0·51	+ 0·47
5½ „	− 0·38	− 0·62	− 0·14	− 0·09	+ 0·26	+ 0·24	+ 0·25
6½ „	− 0·19	− 0·15	− 0·10	− 0·12	+ 0·05	+ 0·12	+ 0·10
7½ „	− 0·17	− 0·20	− 0·11	− 0·12	− 0·02	+ 0·04	+ 0·16
8½ „	− 0·20	− 0·11	− 0·08	− 0·11	− 0·04	+ 0·05	+ 0·04
9½ „	− 0·12	− 0·07	− 0·07	− 0·10	− 0·16	+ 0·03	+ 0·02
10½ „	− 0·09	− 0·05	− 0·13	− 0·09	− 0·03	+ 0·02	− 0·05
11½ „	− 0·11	− 0·09	− 0·09	− 0·15	− 0·05	− 0·07	− 0·12
12½ „	− 0·11	− 0·06	− 0·04	− 0·18	− 0·12	− 0·10	− 0·15
Mean hour angle of the moon at 6½ A.M.	h. 18·06	h. 17·04	h. 16·07	h. 15·05	h. 14·05	h. 13·10	h. 12·05

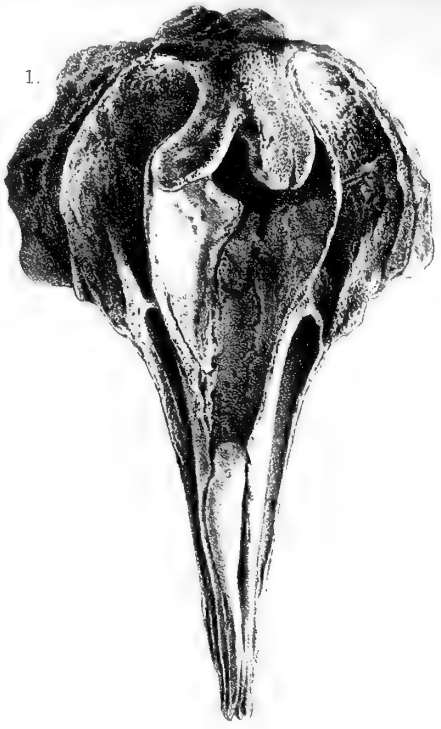
58. If we now examine the epochs near sunset, we find that on the first day the needle has turned (though little) an hour before the sunset observation; on the second day it turns at the sunset observation; on the third day the movement is arrested, or nearly so, from sunset to sunrise; on the fourth day the movement westwards ceases at sunset; on the fifth day it has begun to move eastwards an hour before; on the sixth, two hours before; and on the seventh, one hour before the observation nearest sunset. I think there is little doubt that there is a relation betwixt the direction of movement and sunset like that

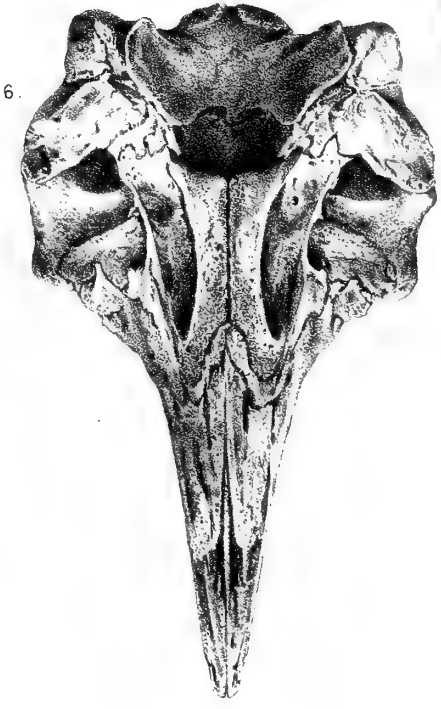
* The means for 12½ A.M., are calculated for the end of each day as well as for the beginning, in order to connect in the projection the value for the end of each day with that for the beginning of the next.

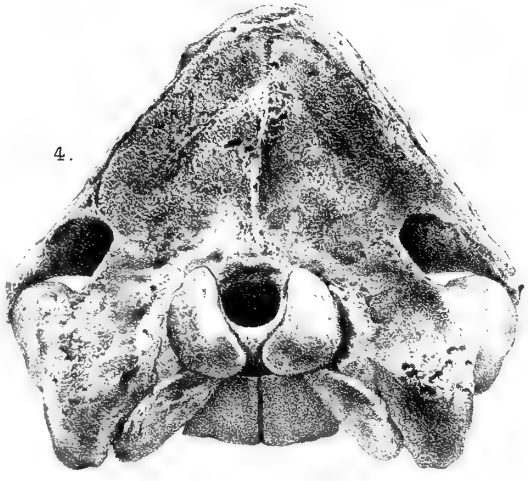
for sunrise, but not so well marked. The curves, Plate XXVII., for the moon's phase seem to show that the turning point occurs generally within two hours of sunset, but these are derived from the superposition of successive days, and are, in consequence, less fitted to show the facts exactly than the curves from the single days under consideration.

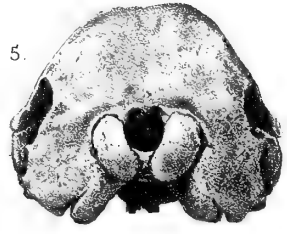
It is instructive to remark the differences of the results from the various calculations. In the last few single days we see how the needle behaves under the influence of the moon on different meridians, in different circumstances of day and night, of sunrise and sunset. In the former, we have results which always diverge more from the true movements, the greater the number of successive days or months which are included in the calculations.

BRITISH MUSEUM NATURAL HISTORY









P. Thomson, photo.

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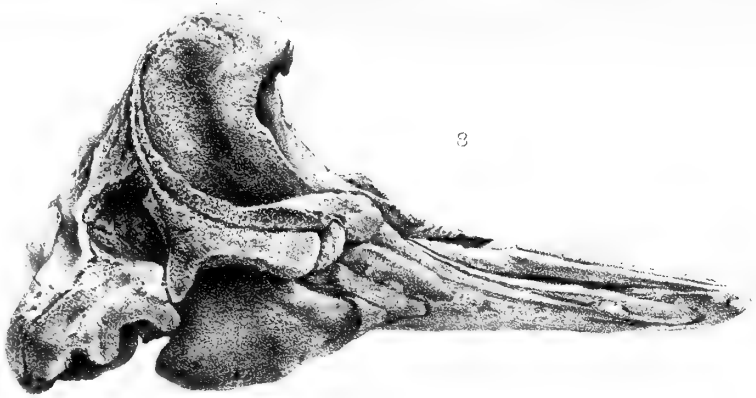

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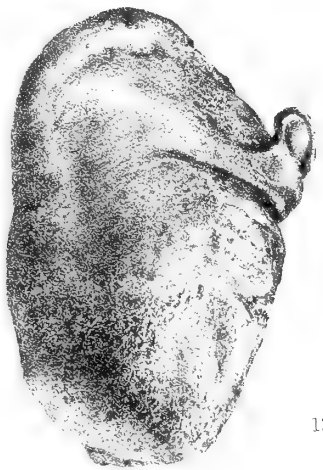

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XXV.—*On the Occurrence of* Ziphius cavirostris *in the Shetland Seas, and a Comparison of its Skull with that of Sowerby's Whale* (Mesoplodon Sowerbyi). By Professor Turner. (Plates XXIX., XXX.)

(Read 20th May 1872.)

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The illustrious Cuvier, in his treatise "Sur les Ossemens fossiles,"* described and figured an imperfect skull which had been obtained, in 1804, by M. Raymond Gorsse in the department of Bouches-du-Rhône, near Fos, on the southern coast of France. It had been found on the sea-shore in the preceding year by a peasant. Cuvier recognised it to belong to an undescribed genus of cetaceans, to which he gave the name of Ziphius; and from the deep hollow which it possessed at the base of the rostrum, he named it *Ziphius cavirostris*. From the condition of the bones, and the general characters of the specimen, he judged it to be a fossil. Cuvier's description, though brief, and from a mutilated specimen, yet clearly states the most salient features of the skull.

This idea of the fossil nature of the cranium prevailed amongst zoologists until 1850, when M. Paul Gervais carefully re-examined Cuvier's specimen, and compared it with the somewhat mutilated skull of a Ziphioid whale, which had been stranded, in the month of May 1850, at Aresquiès, in the department of Hérault, on the Mediterranean coast of France.† From this re-examination and comparison he not only pronounced Cuvier's specimen to be not a fossil, but that the skull of the animal stranded at Aresquiès was specifically identical with the cranium from Fos; and since that time the non-fossil nature of the Fos specimen has been generally admitted.

* Tome v. première partie, 350, fig. 3, pl. xxvii. Paris, 1825.

† Annales des Sciences Naturelles, 3d series, xiv. 1850; also "Zoologie et Paléontologie Françaises," 1re ed. p. 154, et 2me ed. p. 287. M. Gervais has, in order to give an opportunity for making a comparison, reproduced figures of Cuvier's specimen, both in his "Zool. et Pal. Françaises," and in pl. xxi. of the "Ostéographie des Cétacés."

The specific identity of these two crania, however, has been called in question by more than one zoologist. M. Duvernoy regarded the skull from Aresquiès as more closely related to the genus Hyperoodon, and named it *Hyperoodon Gervaisii.** M. Fischer considered it to be another species of the genus Ziphius, and named it *Z. Gervaisi*;† and Dr. J. E. Gray has associated it with the genus Epiodon, and termed it *Epiodon Desmarestii.*‡

In 1864 the cranium of a Ziphius was found at Lanton, on the shore of the Bay of Arcachon, on the Atlantic coast of France. It has been preserved in the Museum of the Scientific Society of Arcachon, and has been carefully examined by M. Fischer,§ who pronounced it to be specifically identical with Cuvier's specimen. The skull is in a good state of preservation, but the lower jaw is wanting.

The attention of naturalists in France having thus been particularly directed to the occurrence of one or more species of Ziphius in the adjacent seas, a careful examination of zoological literature has been made with the view of ascertaining if any cetaceans had been described by other naturalists which could be referred to the same genus. MM. Gervais, Duvernoy, and Fischer agree in considering that a cetacean, stranded on the shores of Corsica, and described by M. Doumet in 1842‖ as a Hyperoodon, is really a member of the genus Ziphius. Fortunately the skeleton has been preserved by M. Doumet at Cette, a brief description of which has been published by M. Fischer, in the form of an appendix to his memoir, and a drawing of the cranium has been reproduced by M. Gervais, in plate xxi. of the "Ostéographie des Cétacés,"¶ now in course of publication, and there can be no doubt that it resembles in its configuration the crania from Fos and Arcachon. Attempts have been made by some naturalists to show that a cetacean, named by Rafinesque *Epiodon urganantus,* one described by Risso as *Delphinus Desmaresti,* and one described by Cocco as *Delphinus Philippii,* are specimens of the same animal; but, as M. Fischer has pointed out,** the descriptions which have been recorded of these animals are too indefinite to enable the zoologist to state with certainty that they belong to the genus Ziphius.

In a short paper on Ziphioid Whales, published in "Nature,"†† Professor W. H. Flower, of London, states that a complete skeleton of an adult *Ziphius* obtained at Villa Franca in 1867, by Professor Haeckel, is mounted in the Anatomical Museum of the University of Jena. But no description has been as yet given of this skeleton. All the five European specimens which have

* Ann. des Sciences Nat. xv. 1851, p. 49.
† Nouvelles Archives du Muséum. Paris, 1867, p. 55.
‡ Catalogue of Seals and Whales in the British Museum, London, 1866; and Supplement, 1871.
§ Comptes Rendus, 1866, Aug. 6; and in Nouvelles Archives du Muséum. Paris, 1867.
‖ Revue Zool. Soc., Cuvier, 1842, pp. 207, 208.
¶ Plate xxi., figs. 8 and 9. Paris.
** *Op. cit.*, p. 58, *e.s.*
†† December 7, 1871.

hitherto been recorded, excepting that from Arcachon, have been obtained on the shores of the Mediterranean.

But from other parts of the world recent crania of Ziphioid whales have been procured, which are closely allied to, if not specifically identical with the European species. In 1863, M. Van Beneden described by the name of *Ziphius indicus** a perfectly adult skull, brought from the Cape of Good Hope, which he thought had been obtained from an animal captured in the Indian Ocean; hence the trivial name *indicus* by which he designated it. This skull is now in the Museum of the University of Louvain. In 1865, Dr J. E. Gray described by the name of *Petrorhynchus capensis*† the cranium of another Ziphioid sent from the Cape of Good Hope by Mr E. L. Layard. An excellent description of the beak of this skull, and the region of the pre-nasal fossa, with illustrative figures, has been given by Professor Owen,‡ who altogether condemns the attempt made to exalt this specimen into a new genus, and ranks it along with the skull described by Van Beneden as an example of *Ziphius indicus*.

In August 1865, Dr Burmeister, of Buenos Ayres, obtained a young male Ziphioid, 13 feet long, which had been stranded near that city. He has described and beautifully figured the external form of the animal, its visceral anatomy, and the skeleton.§ Owing to its youth, the teeth were still imbedded in the gum, and not only were two large teeth observed at the point of the lower jaw, but from thirty to thirty-two small teeth were counted in the gum on the mandible, and twenty-five on each side in the gum of the upper jaw. Burmeister provisionally named the animal *Delphinorrhynchus australis*, and shortly afterwards proposed to call it *Ziphiorrhynchus cryptodon*. Subsequently he adopted Dr Gray's generic name *Epiodon*, and, after suggesting as specific names successively *cryptodon* and *patachonicum*, finally decided on *Epiodon australe*.

Description of the Shetland Ziphius.—In the autumn of 1870, I purchased through one of my pupils, Mr M. Coughtrey, from Mr John Anderson of Hillswick, Shetland, a number of cetacean bones, chiefly those of a large Rorqual (*Balænoptera Sibbaldii*), which had been stranded in October 1869, in Hamna Voe, on the north-west coast of the main Island. Along with the Rorqual Mr Anderson sent the skull of a smaller whale, which he informs me was captured in 1870 off Hamna Voe, out at sea, and towed to the shore. When this skull came into my possession it was invested by the dried and hardened textures

* Mém. Couronnés de l'Acad. Royale de Belgique, 6th June 1863. Collection in octavo, vol. xvi. 1864. Plate i.

† Proc. Zool. Soc. 1865, and Catalogue of Seals and Whales, 1866.

‡ British Fossil Cetacea of the Red Crag, in the Memoirs of the Palæontographical Society, vol. xxiii. 1870.

§ Annals of Natural History, 1866, vol. xvii. pp. 94, 303, plates iii., vi.; also in Anales de Museo Público de Buenos Aires, Tomo i. 1868. Pl. xv.–xx.

of the head, so that although I judged it to be a member of the Ziphioid group of whales, yet I was unable to submit it to a sufficiently close examination to determine the species, until after it had been for some months in the macerating trough. When the bones were cleaned I had no difficulty in deciding that it resembled the *Ziphius cavirostris* of Cuvier. As the Shetland specimen is the first example of this rare cetacean which has been met with in the British seas, I have the satisfaction of adding this animal to the list of British mammals.

From the size of the skull and the condition of many of the sutures, it was obviously that of an adult, if not an aged animal; and as it had not been injured, and the lower jaw was preserved, I am enabled to describe and figure a perfect specimen of this part of the skeleton.

The general outline of the skull was triangular, with curved sides, the base at the occiput, and the apex at the tip of the beak. The summit of the skull was formed by the two nasal bones, the frontal and the upper borders of the two pre-maxillæ. Its greatest length measured in a straight line was $35\frac{1}{4}$ inches; its greatest breadth between the post-orbital processes of the frontal, $21\frac{1}{2}$ inches; its greatest height, $18\frac{1}{4}$ inches.

When regarded from the dorsal surface, the skull was seen to slope rapidly downwards and backwards, from the summit to the foramen magnum and occipital condyles. The slope forwards to the tip of the beak was much more prolonged, so that a far larger proportion of the antero-posterior diameter of the skull was in front of the summit than behind. The beak was triangular in form. Its breadth, on a line with the superior maxillary foramina, was 12 inches; its length from that line to the tip was $19\frac{3}{4}$ inches, and its breadth at the tip $1\frac{1}{4}$ inch.

The tip of the beak was formed by the two pre-maxillaries and the meso-rostral bone. The pre-maxillæ varied much in shape and size in different parts of their extent. Near the tip they were elongated and almost straight, but about 6 inches from the tip their upper borders curved inwards, so as partially to overlap the meso-rostral bone. Here also they diverged from each other and became more expanded; and as they were traced backwards, this divergence and expansion became more strongly marked. At their hinder ends they mounted upwards to assist in the formation of the summit of the skull. Those parts of the pre-maxillæ which lay behind the meso-rostral bone formed the sides and a portion of the posterior boundary of the great pre-nasal cavity at the base of the beak, from the presence of which the specific name of *cavirostris* was applied by Cuvier. The upper borders of these bones, which in the rostrum were curved inwards, and separated by an interval of about 2 inches, at the sides of the pre-nasal fossa were so far everted as to be $8\frac{1}{2}$ inches asunder, a measurement which expresses the transverse diameter of the fossa. The two bones in the pre-nasal region were far from symmetrical. The right was much more expanded

than the left, and its inner surface was directed forwards and inwards, whilst that of the left was more vertical, and to a great extent directed inwards. The upper end of the right bone mounted also higher than that of the left, and formed a thick and strong lobed projection, which overhung the pre-nasal fossa and the orifice of the right nostril. The summit of the left bone was thinner, less curved, less projecting, and more ridge-like than lobed. A nervo-vascular canal of some size opened on the inner concave surface of each pre-maxilla, about 4 inches behind the posterior end of the meso-rostral bone.

The meso-rostral bone formed one of the most characteristic features of the skull. It occupied the interval between the anterior ends of the pre-maxillæ. Near the tip it was narrow, and so intimately blended with the other bones of the beak, that a faint superficial groove on each side was the only indication of their original separation. But where the pre-maxillæ began to diverge, then the meso-rostral bone dilated to a thick dense bar, $2\frac{1}{8}$ inches wide in its greatest transverse diameter, which extended backwards to $13\frac{1}{4}$ inches behind the tip of the beak. At the same time, the grooves marking its separation from the pre-maxillæ increased in depth and breadth, more especially on its left side. Hence this bar was not absolutely mesial, but had a slight inclination to the right side. At its hinder end it abruptly ended in an almost vertical, truncated smooth face, which became continuous with the vomer, where that bone formed the floor of the hollow of the beak. There can be no doubt but this bar rested on the anterior part of the vomer, and was anchylosed to it. At the tip of the beak the meso-rostral bone seemed as if subdivided into two lateral halves by a longitudinal cleft, but I am inclined to think that this cleft was rather to its left side, and marked the separation of the bar from the left lateral half of the vomer, the separation of which, again, from the corresponding pre-maxilla was indicated by a shallow groove.

The two nasal bones were situated between the summits of the two pre-maxillæ, and presented flattened surfaces superiorly. They were inclined forwards and to the left, and, with the lobe of the right pre-maxilla, overhung, like the eaves of a house, the apertures of the nose. They were firmly anchylosed to each other, to the frontal, pre-maxillæ, and mes-ethmoid, and only faint traces of the original sutures remained. The right nasal, which was rather the longer of the two, was 6 inches in its antero-posterior diameter, by $1\frac{1}{2}$ inch in its transverse diameter.

The mes-ethmoid portion of the nasal septum was curved to the left, so that the nasal fossæ were unequal in size, the right being $2\frac{6}{8}$ inches in antero-posterior, and 2 inches in transverse diameter; the left being $2\frac{5}{8}$ inches in antero-posterior, and only $1\frac{3}{8}$ inch in transverse diameter. The upper border was sharp, and prolonged into a spine at its junction with the anterior border. The anterior border expanded into a smooth surface $1\frac{6}{8}$ inch broad at its greatest

transverse diameter. This surface was in the hollow of the beak, and formed indeed a part of the posterior boundary of the floor of the great pre-nasal fossa. It was separated by a suture from the vomer, and the distance between this suture and the posterior truncated end of the meso-rostral bone was $6\frac{3}{4}$ inches. The smoothness, not only of the truncated surface of the meso-rostral bone, but of the expanded anterior border of the ethmoid, induced me to think that the bar of cartilage, which had undoubtedly connected them together in the young state of the skull, had either altogether, or to a large extent, disappeared prior to maceration. For in the skeletons of the Cetacea when unossified cartilage is continuous with the end of a bone, the surface of bone in apposition with the cartilage possesses a faintly tuberculated appearance, such as one is familiar with on the attached surface of an epiphysis of a human bone.

The vomer formed the anterior part of the floor of the pre-nasal fossa, and passed backwards to embrace the inferior border and the sides of the mes-ethmoidal part of the nasal septum. The backward prolongation of the vomer on the left side of the mes-ethmoid was partially concealed by short yet strong bars of bone connecting the left pre-maxilla with the mes-ethmoid. The posterior or cerebral surface of the mes-ethmoid was expanded laterally, and instead of being perforated into a cribriform plate, possessed only a single foramen on each side, in all probability for the transmission of a nasal branch of the fifth cranial nerve.

The superior maxilla formed the side of the beak, but did not extend to within $2\frac{1}{2}$ inches of the tip. For some distance backward it was a comparatively narrow bar of bone, having a deep furrow along its line of articulation with the pre-maxilla; but opposite the large maxillary foramen it expanded both vertically and transversely, overlapped the anterior surface of the frontal, and formed a deep maxillary fossa immediately to the outer side of the upper and posterior end of the pre-maxilla. The free surface of this part of the bone was pitted with irregular shallow depressions, and perforated by a large canal.

An ecto-maxillary ridge, faintly grooved at its free border, extended along the outer edge of the maxilla, and at the base of the beak was elevated into a maxillary tuberosity, sufficiently large to form a noticeable feature in the profile view of the cranium. The maxillo-premaxillary furrow extended backwards immediately to the inner side of this tuber to become continuous with the deep maxillary fossa, and the large maxillary foramen opened into it at the inner side of the tuber. In *Globio-cephalus*, and in various others of the toothed whales, the pre-maxilla does not so completely overlap the superior maxilla, but that a portion of the latter bone appears on the surface to the inner side of the pre-maxilla, and intervenes between it and the nasal. In *Z. cavirostris*, on the other hand, owing to the incurvation of the pre-maxilla, the portion of the superior maxilla above referred to was thrown into the outer wall

of the nose, and, so far as the state of the sutures allowed me to judge, the pre-maxilla seemed to be directly anchylosed to the nasal bones.

The inferior surface of the beak, triangular in its general outline, was convex from side to side, and the convexity gradually increased from before backwards. The tip consisted of the two pre-maxillæ, behind which the superior maxillæ formed this surface of the beak, except in the mesial line, where a narrow bar of bone—the lower edge of the vomer, nearly 10 inches long—came to the surface of the palate. No definite anterior palatine foramen was seen, but a distinct posterior palatine canal was situated on each side at the articulation of the superior maxilla and palate bones.

The palatine plate of the palate bone was little more than 1 inch in antero-posterior diameter at its widest part. The anterior margin was convex, and as the superior maxillæ extended backwards for some distance between the two palate bones, the latter only articulated with each other in the mesial line for about $1\frac{1}{2}$ inch. Laterally each palate bone extended backwards and outwards as far as the lachrymal, a thin scale of the superior maxilla intervening between it and the malar.

The two palate bones were inserted between the anterior borders of the pterygoids, which bones articulated with each other for 7 inches in the mesial line of the under surface of the skull, and formed on each side of this line a well-marked curved ridge, which extended as far back as the posterior orifice of the nose. This orifice was bounded below and at the sides by the two pterygoids, and above by the expanded part of the vomer, the latter of which articulated by the margins of its expanded part with the base of the pterygoids. The vertical and transverse diameters of this orifice were almost equal—between 5 and 6 inches. Owing to the great backward development of the pterygoids, the thick posterior edge of the vertical plate of the vomer, forming the nasal septum, was $5\frac{3}{4}$ inches in front of the posterior margin of the palatal plates of the pterygoids. The vertical plate of the vomer was in the mesial plane, so that the want of symmetry displayed at the anterior nares did not exist at the posterior nostrils. Deeply within the nose a narrow bar of the palate bone could be seen on each side, intercalated between the pterygoid and the side of the vomer. The outer surface of the pterygoid was hollowed into a very shallow fossa, which was not, however, closed in front and externally by a reflected plate of bone, to form a posterior palatine air sinus, as in *Globio-cephalus* and most other cetaceans.

Behind the expanded part of the vomer the basis cranii, deeply concave from side to side, owing to the lateral elevations of the basi-occipital, extended backwards to the foramen magnum. All trace of the suture between the basi-sphenoid and basi-occipital had disappeared, and the anchylosis of the various elements of the occipital bone with each other was perfect.

The occipital surface of the skull, broadly triangular, ascended almost vertically to near the summit of the cranium, where it articulated with the frontal. The foramen magnum, directed backwards, was of almost equal diameter (about $2\frac{1}{4}$ inches) vertically and transversely. The occipital condyles were inclined obliquely downwards and forwards at the sides of the lower half of the foramen, but did not coalesce. Their faces were smooth, convex, and directed backwards and outwards. A vertical, but not quite mesial, ridge ascended from the foramen to the summit of the supra-occipital. No trace of an interparietal bone was seen. The ex-occipital, broad and thick, was prolonged at its outer and lower part into a thick process (par-occipital or jugal), which was separated by a deep cleft from the lateral elevation of the basi-occipital.

The temporal was an irregular bone, situated in front of the ex-occipital with which it articulated. The part, jointed with the jugal process of the latter, had not only the shape of a mastoid process, but was articulated with the squamous temporal by a strongly denticulated suture. A strong zygomatic process arched forwards, and almost touched the post-orbital process of the frontal. A thinner, more scale-like portion of the temporal ascended to form a part of the floor of the temporal fossa, where it articulated with the parietal. The under surface of the temporal bone presented two concavities: an antero-external, or glenoid, for articulation with the lower jaw, and a postero-internal, for the lodgment of the petro-tympanic bone.

The recess for the lodgment of the petro-tympanic bone was of small size, and bounded by the basi and ex-occipitals, and by the squamous and mastoid parts of the temporal. The petrous bone was not anchylosed to the tympanic; it was $2\frac{1}{4}$ inches long by $1\frac{1}{2}$ inch in its greatest transverse diameter, though its outline was irregular. Externally it passed for some distance behind the mastoid, with which it articulated by a smooth flattened surface, whilst its inner end was in apposition with a smooth, almost vertical process of the squamosal, $1\frac{1}{2}$ inch in length. The canal in the bone for the auditory nerve was relatively small. The surface of the bone, forming the inner wall of the tympanum, had the solid, rod-like stapes articulated by a movable joint with the foramen ovale; the incus and malleus had not been preserved. Opening into the recess in which the petrous bone was lodged, was a circumscribed canal, communicating with a cranial cavity obviously for the transmission of the seventh nerve. Between the ex- and basi-occipital were two canals, apparently for the transmission of the eighth and ninth nerves. Somewhat in front of, and internal to the base of the vertical process of the squamous, was another canal situated in the ali-sphenoid, which had probably transmitted the inferior maxillary division of the fifth nerve.

The tympanic bone, $2\frac{3}{8}$ inches in length by $1\frac{7}{8}$ inch in greatest transverse diameter, possessed the conchoidal form so characteristic of this bone in the

Cetacea. Its convex superficial aspect was comparatively smooth; from the antero-external thin border a tongue-like curved process projected forward; whilst the opposite rounded border was crenulated. The bone corresponded closely in form with the tympanic bone of *Hyperoodon*.

The parietal bone was small in size, and seemed not to extend beyond the temporal fossa, a portion of the floor of which it formed. The suture along its upper border was, however, too faint to enable the exact extent of the bone to be accurately observed.

The great lateral crest of the cranium was formed by the narrow free border of the frontal appearing between the superior maxilla and the supra-occipital. Above the orbit, however, the frontal widened out to form an arched roof for that chamber, and terminated both in front and behind in a process—the pre- and post-orbital. A large canal, obviously the optic, opened into the deeper part of the orbit. One inch in front of this canal was an oval opening leading into a deep fossa, into which two canals opened, one leading backwards into the cranial cavity, the other forwards to the great maxillary foramen. These canals doubtless served for the transmission of the ophthalmic and superior maxillary nerves.

But a small part of the great wing of the sphenoid appeared on the under aspect of the skull, as it was extensively overlapped by a thin plate of the pterygoid. A portion of this wing, however, ascended into the temporal fossa, and articulated with the squamoso-temporal, parietal and frontal. This fossa had no great size, but possessed some depth. It was bounded by the frontal with its post-orbital process, by the zygomatic and by the ex- and supra-occipitals.

The malar consisted of a rough plate of bone intercalated between the superior maxilla and the lachrymal, and of a flat, smooth, slender process, which passed backwards for a short distance to form the lower boundary of the orbit. This process was broken on both sides of the skull, so that its proper length could not be ascertained.

The lachrymal was a large plate-like bone, which closely articulated with the orbital surface of the frontal, and entered into the formation of the anterior part of the roof of the orbit. Its anterior border was wedged in between the malar, superior maxillary, and frontal bones.

With the exception of the meso-rostral bone, the petro-tympanics, the nasal septum, and the pre-maxillæ, the bones of the skull were of a loose spongy texture, even on their surfaces—a circumstance which will, doubtless, account for the mutilated condition of almost all the crania of this Ziphioid which have come under the notice of the anatomist.

The lower jaw consisted of two lateral halves anchylosed at the symphysis. Viewed in profile, the upper and lower borders were concavo-convex. The concavity on the upper border was partly on a line with and partly behind the

symphysis, that on the lower border was altogether behind the symphysis. The anterior half of the upper border was marked by a shallow groove, as if for the lodgment of rudimentary teeth, though none were found in the specimen. Quite at the anterior end of the bone, on each side of the symphysis, was a large alveolus, about three-fourths of an inch in diameter, in which at one time the large mandibular tooth had undoubtedly been lodged, but this socket was now occupied by coarsely spiculated bone. The length of the mandible was $32\frac{1}{2}$ inches; the length of the symphysis, 7 inches; the width between the articular condyles, inside measurement, 17 inches. The condyle was situated about the middle of the posterior border of the bone. When articulated with the skull, the lower jaw projected so far beyond the rostrum that the mandibular teeth would, if present, have been altogether in front of the beak.

Comparison of the Shetland Ziphius with previously recorded Specimens.—I propose now to compare the Shetland cranium with the figures and descriptions which have been published of four of the five European,* and the three exotic specimens referred to in the historical introduction, with the object of determining whether they represent different genera, or whether they belong to one or more species of the genus *Ziphius*. In their general configuration all the skulls closely correspond with each other, but as the peculiarly constructed beak and the pre-nasal fossa with the bones which form its boundaries constitute the most distinctive features of these crania, my attention has more especially been directed to a comparison of the forms and relations of the bones which enter into their construction.

In my description I have named the dense, solid bar in the middle of the beak the meso-rostral bone. This bar corresponds with the "vomer" of Cuvier, Gervais, and Gray, with the "anterior tuberosity of the vomer" of Fischer, with the "continuation of the pre-frontals forward to near the end of the pre-maxillaries" of Owen,† and with the "anterior prolongation of the ethmoid" of Flower.‡ Whatever name be applied to it, there can be no doubt that it is an ossification of the anterior end of the long cartilaginous bar, which in the cetacea is prolonged forwards to the end of the beak, and in relation to the sides and lower surface of which the spout-like vomer is formed. In the specimens recorded by Cuvier, Fischer, Doumet, Van Beneden, and Gray and Owen, the meso-rostral bar, as in my Shetland specimen, was strongly pronounced. Slight differences do, however, undoubtedly exist in the shape of this bone in these crania. In those described by Fischer, Gray and Owen, and myself, the posterior end is a little more truncated than in those recorded by Cuvier,

* No figure or description of the Villa Franca specimen in the Jena Museum, so far as I can ascertain, has yet been published.

† Report of British Association, 1846, p. 226, and British Fossil Cetacea of the Red Crag, p. 27.

‡ Introduction to the Osteology of the Mammalia, p. 191. London, 1870.

Doumet, and Van Beneden; and in the two exotic crania it is more swollen, and projects somewhat higher above the pre-maxillæ than in the European skulls. In the Cape cranium, figured by Gray and Owen, it is more mesial and uniformerly tapering from behind forwards than in the Shetland specimen, and in those described by Doumet and by Fischer. But these are all differences so trifling in degree, as not to exceed that range of individual variation which one often meets with in comparing a series of crania of the same species of animal, and which may easily be accounted for by one skull being a little more advanced in its ossification than another.

In my account of the pre-nasal fossa in the Shetland skull, and of the "septum narium," and its relations to the vomer, I might indeed have adopted almost *verbatim* the description which Owen has given of these parts in the Cape cranium, so well does it express the arrangement. Similarly, the form and relations of the nasal bones, the configuration of the upper ends of the pre-maxillæ and superior maxillæ, the form of the palatine surface of the beak, and the relations of the bones which enter into its construction, are identical in all the specimens in which they have been described.

There can be no doubt, in my opinion, that all these crania, whether exotic or European, should be referred to the genus *Ziphius*, and in so far I cordially concur with the remarks made by Professor Owen, that there should be "a tacit burial and oblivion" of the ill-defined generic names with which systematic zoology has of late been needlessly and unscientifically encumbered. I also hold that the crania from Fos, Corsica, Arcachon, and Shetland, are specifically identical, and that the "type" of the species is the *Ziphius cavirostris* of Cuvier. But further, from a comparison of the Shetland cranium with the figures and descriptions of the two specimens from the Cape, I am of opinion that they should not be separated from Cuvier's "type" species by the distinctive name of *Ziphius indicus*. In recommending a new specific name for his Cape skull, M. Van Beneden appears to have taken Gervais' specimen from Aresquiès, in which the meso-rostral bone is absent, as the type of *cavirostris* rather than Cuvier's original example, in which it is well developed, just as in the crania from Corsica, Arcachon, Shetland, and in Van Beneden's own specimen. He also refers, as another feature of difference, to the absence of teeth in the upper jaw in his specimen, and their presence in the gum of the upper jaw in the Aresquiès cranium. But these teeth were quite rudimentary and functionless, and the presence of such aborted organs ought no more to form a basis for establishing a specific difference than should the entire absence of teeth, both in the upper and lower jaw, in the Shetland cranium be a reason for regarding it as a distinct species. Further, there is no evidence that teeth were present in the upper jaw in Cuvier's type-specimen, or in the skulls from Corsica and Arcachon. Moreover, both in Van Beneden's Cape skull and in the one from

Shetland, the lachrymal bone was very distinct, and the mastoid part of the temporal was a separate ossification. The tympanic bone also, as figured by Van Beneden, closely corresponds in shape to that of the Shetland cranium.

There is, however, greater difficulty in coming to a positive conclusion as to the specific position of the cranium from Aresquiès described by Gervais, and that from Buenos Ayres by Burmeister. These skulls agree in possessing the characteristic hollow at the base of the beak, but they differ from the specimens above referred to, in possessing an open meso-rostral canal, extending along the whole length of the beak, and in the consequent absence of a meso-rostral bone. Gervais' specimen not only had rudimentary teeth, but it is also stated by Fischer that the nasal fossæ were not so deflected to the left, and the hollow of the prenasal fossa was not so great as in the skull from Arcachon. Gervais himself does not regard these differences as sufficient to form a new species, and refers the Aresquiès cranium to *Z. cavirostris.* Fischer, however, considers them to be of specific value, and gives the specimen the name of *Z. Gervaisi.* Burmeister's specimen was admittedly a young male, and not only were rudimentary teeth, as in Gervais' specimen, present in the gum, but a strong cylindrical cartilage occupied the canal between the two intermaxillary bones. Should the non-ossification of the anterior end of this cartilage be a persistent condition in these animals, even in adult life, then they would undoubtedly have to be regarded as forming species distinct from *cavirostris.* But if the want of ossification of the cartilage is due, like the presence of rudimentary teeth, merely to the youth of the animals—and as the conversion of the anterior part of this cartilage into bone is altogether an exceptional occurrence in the cetacea, it is possible that it may not take place in the genus *Ziphius* until towards the end of the period of ossification—then these characters cannot be adduced as satisfactory evidence of a specific difference. I am disposed, until further information has been obtained regarding this question, to rank provisionally these crania also with *cavirostris,* which will include therefore the following specimens :—

Ziphius cavirostris.

Fos, Bouches du Rhône, . . .	Cuvier.
Aresquiès, Hérault, ...	Gervais.
Corsica, ...	Doumet.
Cape of Good Hope, . . .	Van Beneden.
Arcachon, ...	Fischer.
Cape of Good Hope, . . .	Gray and Owen.
Buenos Ayres, ...	Burmeister.
Villa Franca, ...	Haeckel.
Shetland, ...	Turner.

If this mode of regarding the specific unity of these specimens be correct, then *Ziphius cavirostris* will have a geographical range equal to that possessed by the spermaceti whale.

Historical Sketch of Sowerby's Whale.—Early in the present century, Mr James Sowerby figured and gave a short description* of a new species of cetacean cast ashore in 1800, near Brodie House, county of Elgin, which he termed *Physeter bidens*, or the two-toothed Cachalot. The animal was a male, and the beak, with the anterior part of the cranium and the lower jaw, are preserved in the Oxford University Museum. De Blainville associated the name of Sowerby with this animal, and since then the specific name *Sowerbyi*, or *Sowerbiensis*, has been attached to it, although with varying generic appellations. For whilst some zoologists class it as a species of the genus *Ziphius*, by others again the generic name of *Mesoplodon*, given by M. Gervais, is not unfrequently accepted. In 1864 another specimen, also a male, was stranded in the Bay of Brandon, on the coast of Kerry in Ireland, and the head has been figured and described by Mr William Andrews.† The skull is preserved in the Museum of the Royal Dublin Society. At a meeting of the Royal Irish Academy, June 23, 1870, Mr Andrews mentioned that a second specimen, 17 feet in length, had been captured in the same locality, in the month of May of that year.‡ Other animals belonging to the same species have been stranded on the coasts of the continent of Europe. A female at Havre, near the mouth of the Seine, in 1825, described by Cuvier as *Delphinorhynchus micropterus*, the skull of which is in the Museum of Natural History, Paris.§ Another female stranded at Sallenelles, Calvados, in 1825, the skull and part of the skeleton of which are preserved in the Museum at Caen.‖ A young female stranded at Ostend in 1835, the skeleton of which is in the Brussels Museum.¶ A mandible in the Museum at Christiania, found some years ago on the coast of Norway.**

But from the seas of the southern hemisphere specimens have been procured which, though differing in some particulars, yet conform in many essential points with the European examples. In the Museum of Natural History in Paris is a skull brought from the Seychelles Islands, to which the specific name

* British Miscellany, plate i. p. 1. London, 1806.

† Trans. Roy. Irish Academy, Part X. 1869.

‡ Nature, Aug. 11, 1870. [Professor Macalister writes me that the bones of this specimen are still undergoing maceration. Dr J. E. Gray states, "Annals of Nat. Hist.," August 1872, that Mr W. Andrews informs him of the receipt of a perfect male skeleton of this rare whale at the Dublin Museum, being the third specimen taken on the west coast of Ireland.—Note, October 1872.]

§ Hist. Nat. des Cétacés. Paris, 1836; p. 114, plate vii. Figured also by Gervais in "Ostéographie des Cétacés," plate xxvi.

‖ Figured by Gervais in "Ostéographie des Cétacés," plate xxvi.

¶ Dumortier. Mém. de l'Acad. Roy. de Belgique, tom. xii. 1839; and Van Beneden in Mém. Couronnés Coll. in Oct., tom. xvi. plate iii. 1864.

** Van Beneden in "Bulletins de l'Acad. R. de Belgique," xxii. 1866.

densirostris was applied by De Blainville.* A skeleton from Lord Howe's Island, recently obtained by Mr Krefft, has also been referred to the same species.† A skull transmitted by Mr Layard from the Cape of Good Hope to the British Museum, and named in the first instance *Ziphius Layardi* after that naturalist, has recently been described as forming a new genus, *Dolichodon*, by Dr Gray.‡ Mr Krefft has also obtained a whale, 18 feet long, from Little Bay near Sydney, the skeleton of which is in the Sydney Museum;§ he considers it to be a new species, and names it *Mesoplodon Güntheri;* but Mr Flower thinks that it may be of the same species as *Layardi*, but with the tooth much less developed;‖ Dr Gray, however, regards it as a new genus, and proposes to call it *Callidon.*¶ In a paper communicated to the Wellington Philosophical Society of New Zealand, January 1870,** Mr Frederick Knox and Dr Hector figure and briefly describe the skull of a young male Ziphioid whale, 9 feet 3 inches long, killed in 1866 in Titai Bay, Cook's Strait; Dr Gray, though recognising the affinity of this skull to Sowerby's whale, yet because the mandibular teeth are situated at the anterior end of the jaw, refers it to the genus *Berardius*, and terms it *B. Hectori.*†† Lastly, M. Gervais has described and figured by the name of *Dioplodon europæus*‡‡ the skull of an animal frequenting the seas off the department of La Manche on the North Coast of France, which possesses many affinities with Sowerby's whale.

Description of the Skull in the Edinburgh Museum.—The skull, to which I next direct the attention of the Society, I recognised in 1869, when examining the Cetacean crania in the Museum of Science and Art in this city. No label or mark of any kind was attached to it to show that any attempt had been made either to identify the species, or even to record the locality from which it had been obtained. Fortunately the Anatomical Museum of the University possesses, through the courtesy of Dr Acland, a copy of the cast of the original example of Sowerby's whale, so that I had no difficulty, on comparing it with

* Duvernoy called it *Mesodiodon densirostre* (*Ann. des Sc. Nat.*, 1851, xv. p. 58, plate ii.), and Gervais has figured it in "Ostéographie des Cétacés," plate xxv., as *Dioplodon Sechellense.*

† Proc. Zool. Soc., 1870, p. 426; and Gray's Synopsis, p. 102.

‡ Proc. Zool. Soc., 1865; and Synopsis, p. 101. Beautifully figured as *Z. Layardi*, by Professor Owen in his Memoir in Trans. Palæontographical Society, vol. xxiii. plate i.

§ Annals of Natural History, 1871, vii. 368.

‖ Nature, Dec. 7, 1871, p. 105.

¶ Annals of Natural History, 1871, vii. 368.

** Trans. New Zealand Institute, vol. iii. plates xiv. xv. p. 125 *e.s.* In Dr Hector's notes it is stated that plate xiv. refers to a specimen captured in Porirua Harbour, 1866, but this is evidently an error, as Mr Knox informs us that only a rude sketch and a few measurements of that animal were preserved. I am indebted to Dr Lauder Lindsay for the opportunity of consulting these Transactions.

†† Annals of Natural History, 1871, viii. p. 116.

‡‡ Zoologie et Paléontologie Françaises, 2d ed. p. 289. Ostéographie des Cétacés, plate xxiv. Also M. Deslongchamps in Bull. Soc. Linn. Normandie, t. x. 1866. Dr Gray, as if to add one more to the multitude of generic names he has coined in his classification of the Cetacea, calls this specimen *Neoziphius* (*Synopsis*, p. 101).

the cast, in determining it to be a younger skull of that species. As none of the officials connected with the Museum of Science and Art could give me any information as to the history of the specimen, I think it very probable that it had formed a part of the Natural History collection of the University, prior to its transference to the Department of Science and Art in 1854. As the skull is almost perfect, and the bones not quite free from oil, it is clear that the specimen had not been lying about the sea-shore and subjected for a time to the action of the weather, but had been removed from a newly killed animal. It is not unlikely that the animal had been captured somewhere on the Scottish coast, and that the skull had been presented to the late Professor JAMESON.*

The following description of this specimen of the skull of SOWERBY's whale has been written with the especial object of pointing out the features of resemblance and dissimilarity between it and *cavirostris*. The skull of *Sowerbyi* was not only much smaller, but more elegantly formed than that of *cavirostris*. Its greatest length in a straight line was $29\frac{1}{2}$ inches; its greatest breadth, between the post-orbital processes, $11\frac{3}{4}$ inches; its height, $9\frac{3}{4}$ inches. It was obviously not perfectly adult, as the cranial sutures were not obliterated, and the pair of mandibular teeth projected but slightly from their sockets. The texture of the bones was not so open and friable as in *cavirostris*.

The summit of the skull was formed by the frontal and superior maxillaries. The beak was slender, its sides more nearly parallel, and it was absolutely longer than that of *cavirostris*, as the distance from a line drawn across the base between the maxillary foramina to the tip was $20\frac{1}{2}$ inches, whilst its breadth at the same line was only 10 inches. The tip of the beak was formed by the pre-maxillæ, which extended backwards almost horizontally as far as the base of the beak. Their upper borders were curved inwards so as almost completely to roof in the elongated meso-rostral canal, and in no part of their extent were they more than $\frac{5}{8}$ths of an inch asunder. On a line with the base of the beak the pre-maxillæ rapidly ascended, formed the sides of the anterior nostrils, and each terminated superiorly in a roughened, slightly overhanging ridge. The surface of the ascending part of each bone widened out somewhat, and looked almost directly forward, so that no hollow existed at the base of the beak. The pre-maxillæ were almost symmetrical, the right bone being a trifle broader than the left. A foramen opened on the free surface of each bone on a line with the maxillary foramina.

No meso-rostral bone occupied the canal in the middle of the beak, which was quite empty, though with the soft parts *in situ*, it would undoubtedly have contained the elongated mes-ethmoid cartilage.

* I have from time to time pointed out this cranium to various naturalists, amongst whom I may mention Dr GÜNTHER, Dr ACLAND, and Professor VAN BENEDEN. From a reference to it in Professor FLOWER's article in "Nature," already quoted, it would appear that M. VAN BENEDEN had supposed the skull to be at the present time in the University Museum.

The nasal bones, about 2 inches long, were laterally compressed, almost vertical in position, and locked in between the upper overhanging borders of the two pre-maxillæ, which partially concealed them. The nasal septum was mesial, so that the anterior nares were symmetrical. The vertical diameter of the entire orifice was $2\frac{1}{2}$ inches, the greatest transverse $1\frac{3}{4}$ inch. The upper border of the septum was sharp and concave; its anterior border closed in the posterior end of the meso-rostral canal, and was faintly tuberculated as if for attachment to the mes-ethmoid cartilage.

The vomer formed the floor and in part the sides of the meso-rostral canal. It gradually tapered off in front, and did not reach to within $6\frac{1}{2}$ inches of the anterior end of the beak; posteriorly it was prolonged along the sides and inferior border of the mes-ethmoid nasal septum, with which it blended.

The superior maxilla extended only to within $4\frac{1}{2}$ inches of the tip of the beak, and formed a narrow bar of bone, between which and the pre-maxilla only a shallow furrow was seen. Although it expanded rapidly at the base of the beak to overlap the frontal, the maxillary fossa was slight, and the surface of the bone was not pitted. The maxillary foramen was not large and single, but was subdivided into several smaller openings. The ecto-maxillary ridge had a sharp, knife-like edge, and the maxillary tuberosity could scarcely be said even to be indicated.

The inferior surface of the beak flattened at the tip was formed by the pre-maxillæ: at and towards the base it was slightly convex, and consisted of the superior maxillæ; but the intermediate part was faintly concave, and its sides were formed of the superior maxillæ, between which the pre-maxillæ extended backward for some distance, whilst the lower border of the vomer came to the surface in the mesial line for a distance of $6\frac{1}{2}$ inches.

The palatine plates of the palate bones articulated mesially for $1\frac{1}{2}$ inch, and then diverged in front to permit the superior maxillæ to pass backward between them. Each plate stretched out laterally as far as the lachrymal bone. A small posterior palatine foramen was situated close to the right palato-maxillary suture. The two palate bones were in part inserted between the two pterygoids, which also articulated mesially with each other, and passed back to form the sides and floor of the posterior orifice of the nose. Each pterygoid curved outward from the mesial and palato-pterygoid sutures to form a ridge, which overhung the outer surface of the pterygoid, and formed a deeper fossa than was seen in *cavirostris*—an arrangement which presented a closer approximation to a posterior palatine air-sinus than was seen in that animal, though, as in it a reflected plate of bone was not developed. The posterior nasal opening was $2\frac{1}{2}$ inches in height by 3 inches in transverse diameter. As in *cavirostris*, the hinder edge of the vertical plate of the vomer was some distance within the opening, the roof of which was formed by the expanded part of that bone, whilst a

part of the palate bone entered into the construction of the outer wall of the nares.

The basis cranii was concave, owing to the lateral elevations of the basi-occipital. The occipital surface of the cranium was not so vertical as in *cavirostris*, and had a faint mesial ridge. The foramen magnum was $1\frac{7}{8}$ inch high by $1\frac{6}{8}$ inch wide. There was no trace of an interparietal, unless a small process anchylosed to the supra-occipital, and projecting into the mesial part of the frontal, could be thus considered. The ex-occipitals were prolonged externally into a jugal process, which was separated by a cleft from the lateral elevation of the basi-occipital.

The squamoso-zygomatic part of the temporal resembled the same bone in *cavirostris*. Unfortunately, the mastoid and petro-tympanic elements of the temporal had not been preserved in this specimen of *Sowerbyi*. Three canals communicating with the cranial cavity opened into the periotic hollow.

The parietal bone formed a large share of the floor and anterior wall of the temporal fossa, and ascended between the occipital and frontal bones for $1\frac{1}{2}$ inch above the temporal crest. The relations of the frontal bone to the great lateral crest of the cranium were similar to those described in *cavirostris*, but at the summit of the skull, owing to the differences in size, shape, and direction of the two nasals, the frontal passed forwards between the upper ends of the two superior maxillæ, and articulated not only with the nasal but with a narrow process sent backwards from each pre-maxilla. The frontal formed also the roof of the orbit, and possessed a pre- and post-orbital process. An optic and a pre-optic foramen opened into the deeper part of the orbit.

A small part only of the great wing of the sphenoid was visible on the surface of the skull, and it contributed only in a minor degree to the formation of the floor of the temporal fossa, which was chiefly composed of the parietal and squamoso-temporal bones. The malar had the same relations as in *cavirostris*, but the lachrymal was relatively larger than in that animal, for not only did it assist in the formation of the roof of the orbit, but it extended so far outwards and forwards as to articulate with the pre-orbital process of the frontal, and contributed to form the profile outline of the cranium.

The lateral halves of the lower jaw were not anchylosed at the symphysis. Both the upper and lower borders were concavo-convex, but the concavity on the lower border was deeper and proportionally longer than in *cavirostris*, so that the bone had a lighter and more elegant appearance. The upper border possessed in its anterior half a dental groove, and a single large, triangular, laterally compressed tooth was present on each side, only the curved and backward directed apex of which projected beyond the socket. The slight projection of the teeth may, perhaps, be due not merely to the non-adult state of the animal, but may indicate that it was of the female sex. The socket was

situated 9 inches behind the tip of the jaw, and almost on a line with the hinder end of the symphysis. The length of the mandible was $27\frac{1}{2}$ inches, that of its symphysial portion $9\frac{3}{4}$ inches. The symphysis was therefore not only relatively, but absolutely longer in *Sowerbyi* than in *cavirostris*. In the articulated skull the lower jaw projected, as in *cavirostris*, beyond the tip of the beak.

Comparison of this Skull with previously recorded Specimens.—Of the specific identity of the skull in the Edinburgh Museum with Sowerby's original specimen, and with the crania from Havre, Calvados, Ostend, and Christiania, I have satisfied myself, by comparing it with the cast of the skull of the first, and with the published figures of the last-named crania. The Irish specimens also are in all probability of the same species, although, so far as I can ascertain, figures of these crania have not been published. Differences, however, of a very appreciable character exist between the Edinburgh skull, the exotic specimens referred to in the historical sketch, and the skull named *Dioplodon europæus* by Gervais. In the skull from the Seychelles Islands, to which the specific name *densirostris* is usually applied, not only is the want of symmetry more decided, but the meso-rostral canal instead of being empty is occupied by an elongated slender bar of dense bone, and the mandible is thicker and deeper behind the symphysis, where the mandibular pair of teeth project from their alveoli. The skull from the Cape, named *Layardi*, also unsymmetrical, possesses even a more strongly marked meso-rostral bone than *densirostris;* the mandible is not, however, thickened and deepened, but contains a pair of remarkably elongated and curved teeth, which arch upwards and backwards at the sides of the rostrum to meet each other superiorly. Although various zoologists have proposed to give a generic value to the differences exhibited by *Sowerbyi, densirostris,* and *Layardi,* and have made each the type of a distinct genus, yet I agree with Owen that there is nothing in the structural characters of either of the three to justify more than a specific difference. The New Zealand specimen figured by Knox and Hector, though referred by Gray to the genus *Berardius,* is without question much more closely allied to Sowerby's whale. Like *Sowerbyi* it did not possess a meso-rostral bone, but the beak, judging from the figure, was not so slender and elongated, the want of symmetry in the nasal region was greater, and the pair of mandibular teeth were situated close to the tip of the jaw. Some of these differences may, perhaps, be due to the youth of the specimen, but the forward position of the mandibular teeth marks, in all probability, a distinct species.

In the *Dioplodon europæus* of Gervais, the cranium is longer and wider than in *Sowerbyi;* the beak also is wider, owing to the rostral part of the superior maxillæ being more strongly pronounced, and the meso-rostral canal is completely filled by an elongated meso-rostral bone. Moreover, the mandible is not so curved at its upper and lower margins, its symphysis is shorter, and the single

tooth on each side, is situated nearer the tip. But these differences also, I would submit, are of specific and not of generic import. For, although modifications, such as I have described, occur in the construction of the beak, in the form of the lower jaw, and in the position of the mandibular teeth; the conformation of the nasals, pre-maxillaries, and maxillæ, in the region of the anterior nares, presents but slight modifications in *Sowerbyi*, *densirostris*, *Layardi*, and *europæus*. Hence, I am disposed to consider that it is in the region of the anterior nares, and in the bones surrounding these orifices, we are to look in the Ziphioid group of whales for the characters which indicate generic resemblance or dissimilarity, whilst the beak and lower jaw furnish us with the characters on which specific relations may be based.

For if we recur to the group of crania, which in the first part of this memoir I have classed under the head of *Ziphius cavirostris*, we find that they all possess, from the peculiar shape of the pre-maxillæ, a wide and deeply excavated pre-nasal fossa, at the bottom of which the anterior nares open, and that in all the unsymmetrical, lobate nasals, with their shelving pent-house-like projection, overhang the anterior nares. In the construction of the beak modifications such as I have described occur in various of these crania, but in none can these modifications, if they are to be regarded as anything more than mere individual or sexual variations, be considered as marking more than specific differences.

Again, all the crania which I have referred to in the historical sketch of Sowerby's whale, agree with that animal in the absence of a pre-nasal fossa; for in these skulls the pre-maxillæ ascend almost vertically, and with their anterior surfaces so flattened, and the nasal bones so included between them, that the anterior nares open directly, if I may so say, on the anterior plane of the skull, and not at the bottom of a deep pre-nasal fossa. And although in the construction of the beak, in the conformation of the lower jaw, and in the position of the mandibular teeth, differences occur which may fairly be regarded as specific, yet their common naso-premaxillary arrangements unite them, I believe, into a single genus.

Are we then to consider, as has been done by Professor Owen, that Sowerby's whale and its allies belong, like the *cavirostris* of Cuvier, to the genus *Ziphius*, and form distinct species of that genus, or are we to regard them as forming a distinct genus, having various specific subdivisions? The value which I am disposed to attach to the conformation of the naso-premaxillary region in the Ziphioid group of whales, as a basis for classification, leads me to the conclusion that *Sowerbyi*, with its congeners, should be placed in a genus distinct from *cavirostris*. Reserving them for the latter, the name of *Ziphius*, which was originally applied to it by Cuvier, I shall adopt Gervais' name of *Mesoplodon* as the generic designation for *Sowerbyi* and its allies. This genus may be regarded as including the following species :—

MESOPLODON SOWERBYI.

Examples from coast of Elgin, Scotland; Havre; Calvados; Ostend; Norway; Brandon Bay, Ireland; also in the Edinburgh Museum of Science and Art.

MESOPLODON DENSIROSTRIS.

Examples from Seychelles Islands; Lord Howe's Island.

MESOPLODON LAYARDI.

Example from Cape of Good Hope.

MESOPLODON EUROPÆUS.

Example from La Manche, France.

Provisionally also, the specimen captured in Little Bay, near Sydney, and the animal caught in Titai Bay, New Zealand, may be registered as distinct species of the genus *Mesoplodon.*

MESOPLODON GÜNTHERI.

Example from Little Bay, Sydney.

MESOPLODON HECTORI.

Example from Titai Bay, Cook's Strait, New Zealand.

EXPLANATION OF PLATES XXIX., XXX.

The Plates have been lithographed from photographs of the crania, taken under my superintendence by Mr Peter Thomson.

Fig. 1. Dorsal surface of cranium of *Ziphius cavirostris,* reduced nearly one-tenth.
Fig. 2. Anterior nares and pre-nasal fossa of the same animal.
Fig. 3. Dorsal surface of cranium of *Mesoplodon Sowerbyi,* reduced one-ninth. In placing the skull before the camera, the photographer had unfortunately turned it over slightly to the left side, so that the picture is not absolutely a full face view.
Fig. 4. Occipital surface of the skull of *Z. cavirostris.*
Fig. 5. Occipital surface of the skull of *M. Sowerbyi.*
Fig. 6. Palatal aspect of the cranium of *Z. cavirostris.*
Fig. 7. Palatal aspect of the cranium of *M. Sowerbyi.*
Fig. 8. Profile view of cranium of *Z. cavirostris.*
Fig. 9. Profile view of the lower jaw; and
Fig. 10. View of the alveolar borders of the lower jaw of the same animal.
Fig. 11. Profile view of the cranium of *M. Sowerbyi.*
Fig. 12. Profile view of lower jaw of same animal.
Fig. 13. Outer surface of tympanic bone; and
Fig. 14. Outer surface of petrous bone of *Z. cavirostris,* both the size of nature. The stapes *st.* in this specimen is *in situ.*

APPENDIX.—November 23, 1872.

In drawing up the Historical Sketch of Cuvier's Hollow-beaked *Ziphius* and of Sowerby's Whale, I omitted to refer to a brief description by Professor A. W. Malm, in a memoir, entitled "Hvaldjur i Sveriges Museer år 1869,"* of the skeleton of a specimen of each of these rare Cetaceans preserved in the Natural History Museum in Göteborg, Sweden. Although I possessed, through Professor Malm's great courtesy, a copy of his elaborate memoir, yet I had not, owing to its being written in the Swedish language, mastered its contents. My friend, Professor Flower, having within the last few days referred me to Malm's description of these specimens, Dr Charles Wilson has very kindly translated for me the passages in which they are described, and as a knowledge of Swedish is by no means general amongst British zoologists, I think it desirable to append a statement of the more important particulars which Malm has recorded.

The specimen of *Ziphius cavirostris* was found stranded at Holma, near Gullmarsfjärd, Sweden, on 22d April, 1867. It was supposed to have been suffocated by getting under the ice which had formed about Christmas, and was so putrid that only a hand's breadth of dark-grey skin remained. It was a female, and measured 22 feet 2 inches (Swedish) in length. 75 kanns (7500 cubic inches) of oil were obtained from it. In the stomach a tangled mass of a transparent worm, 3 feet long, was found, which apparently belonged to the genus *Echinorhynchus*. The total length of the skeleton, including the cranium, was 6140mm., to which an additional 34mm. must be added for the projection of the lower jaw beyond the beak :—

Length of cranium	1015mm.
„ „ mandible	887 „
„ „ symphysis	205 „
„ „ greatest breadth of skull	570 „

Two teeth, similar in size and shape, were in the lower jaw, but only the point of each was tipped with enamel. The epiphyses were anchylosed to the vertebral bodies. The vertebral formula was—C_7 D_{10} L_{10} Cd_{19} = 46. The four upper cervical vertebræ were anchylosed together. The sternum was subdivided into five pieces, only the two posterior of which were completely

* Konig. Svenska Vetenskaps—Akad. Handlingar. Band 9, No. 2. Stockholm, 1871.

anchylosed. There were nine chevron bones. The constitution of the carpus is represented by MALM in plate v. fig. 51.

The Swedish specimen furnishes, therefore, an additional example to that which I have obtained from Shetland of the occurrence of this Cetacean in the North Sea; a habitat which had, indeed, been given for this animal by Dr. GRAY, in the Supplement (p. 98) to his Catalogue of Seals and Whales, although no example from this sea was particularized by him.

Professor FLOWER writes to me that he has lately seen a fine skeleton of *cavirostris* in the Museum at Pisa. As the Mediterranean is evidently one of the usual habitats of this cetacean, this specimen had in all probability been obtained from an animal stranded on the coast of Italy. Hence it will be necessary to add to the list of specimens given on p. 770 the following examples of

ZIPHIUS CAVIROSTRIS.

Holma, Sweden	MALM
Pisa (Mediterranean)	FLOWER

The specimen of SOWERBY's whale in the Göteborg Museum was found in 1869 by a fisherman upwards of 100 miles from Käringö, Sweden. It was floating vertically in the sea with its long-pointed snout directed upwards, and was much decomposed. It was a male. MALM obtained the entire skeleton, with the pelvic bones *in situ*. The total length of the skeleton, including the cranium, was 4409mm., to which an additional 8mm. must be added for the projection of the lower jaw beyond the beak:—

Length of cranium	733mm.
„ „ mandible	639 „
„ „ symphysis	212 „
Greatest breadth of skull	318 „

In addition to the large tooth usually found on each side of the lower jaw in this animal, MALM's specimen possesses a second small tooth on each side behind the large one, and the grooved character of the alveolar edge of the mandible led him to think that it might at an earlier age have possessed others. The distance from the point of the longer tooth to the point of the symphysis was 240mm. The vertebral formula was—C_7 D_{10} L_9 Cd_{20} = 46. The atlas and axis were anchylosed together, and the epiphyses were united to the bodies of the vertebræ. The sternum consisted of five pieces, only the two posterior of which were completely anchylosed. Chevron bones ten; pelvic bones 63mm. long, 9mm. broad. MALM represents the constitution of the carpus in plate v. fig. 52, and names the specimen *Micropteron bidens*.

XXVI.—*Remarks on the Ipecacuan Plant* (Cephaëlis Ipecacuanha, *Rich.*), *as cultivated in the Royal Botanic Garden, Edinburgh.* By JOHN HUTTON BALFOUR, M.D., F.R.S., Sec. R.S.E., F.L.S., Hon. Mem. Pharm. Soc., and Professor of Medicine and Botany in the University of Edinburgh. (Plates XXXI., XXXII.)

(Read 18th March and 3d June 1872.)

The Ipecacuan plant, *Cephaëlis Ipecacuanha* of ACHILLE RICHARD, has been cultivated in the Edinburgh Botanic Garden for upwards of forty years, but it was not propagated to any extent until 1870, when a proposal was made to attempt the cultivation of the plant in India. This suggestion was made on account of the continued destruction of the plant by the collectors in Brazil, and the risk of scarcity in the supply of this most valuable remedy for dysentery. The Secretary of State for India (His Grace the DUKE of ARGYLL), under the recommendation of several medical officers in Bengal, authorised an attempt to propagate the plant in our Indian possessions, and with that view application was made to me and others to aid in this important undertaking. Accordingly, I at once set about the propagation of the plant in the Edinburgh Garden, with the assistance of Mr M'NAB the curator. He found that the plant could be multiplied very rapidly by dividing the annulated root, cuttings of which, though very small, give off young shoots when placed in favourable circumstances. By this means, numerous plants were produced very rapidly, and the method was also followed by the Messrs LAWSON, Nurserymen, Edinburgh, who supplied a large stock of vigorous plants. Mr M'NAB drew up a report of his mode of propagation, which was printed, and distributed extensively to district officers in India and elsewhere. The paper also appeared in the Transactions of the Botanical Society of Edinburgh, vol. x. p. 318.

In Plate XXXII. fig. 6, two portions of a root giving off leaf-buds are shown.

It appears from a report by Dr KING, Director of the Calcutta Botanical Garden, that in 1866 a single plant of Ipecacuan was received at the Calcutta Garden from Dr HOOKER, but apparently artificial propagation had been attended with sparing success, as Dr KING reported at the beginning of 1872 that "the only surviving offspring of the Kew plant amounted to five plants in Sikkim, and seven in the Calcutta Garden." It is understood that cuttings of the stem were planted, but not of the roots. When, however, the plan proposed by Mr M'NAB was adopted for the propagation of the plant, much greater

success was obtained. In May 1871, a Wardian case was sent from the Edinburgh Botanic Garden containing twelve plants, and in October seventy-four plants were despatched. The greater number of these reached their destination in a good state.* In a report received since the reading of this paper, it is stated, with reference to the late consignment, "These plants were forwarded to Sikkim as soon as practicable after their arrival. The Calcutta climate having proved totally unsuitable to this plant, all attempts to propagate it there have been abandoned. The plants are at present under the immediate care of the European gardeners of the Cinchona plantation, and propagation is being carried on chiefly in one of the hot deep valleys of the Rungbee reserve.

"From what we have been able to learn from observation, Ipecacuanha will apparently thrive best under deep shade, and in a hot, steamy, equable climate. These conditions are supplied most fully in the valleys on the outer slopes of the Sikkim Himalaya, which open toward the Terai. A fine small valley near Sookna, at the point of entrance into the hills of the cart-road from Silligoree to Darjeeling, has accordingly been taken up as an Ipecacuanha reserve. Hitherto the plant has not perfected seed in India, although flowers have frequently been produced; we must therefore look to increase by cuttings and other artificial methods."—(*Gardener's Chronicle, Oct.* 5, 1872, *p.* 1322.)

As regards the specimens in the Botanic Garden, their propagation was accomplished in the first instance by taking cuttings from the roots of a plant sent by Sir WILLIAM HOOKER from the Glasgow Botanic Garden. The original specimen had been forwarded to him by Mr MAKOY of Liege, and it flowered at Glasgow in 1843. (See "Botanical Magazine," tab. 4063.) Propagation from this single stock, however, was not sufficient to meet the requirements of India. I therefore applied for an additional supply of plants to my friend Dr GUNNING, a medical graduate of the University of Edinburgh, who now resides at Palmeiras, near Rio Janeiro. Sir ROBERT CHRISTISON also aided me in this request, and has continued to take a deep interest in the matter. By Dr GUNNING's kind services, we were able to secure a considerable supply of plants from Brazil—the roots of which, by division, have yielded abundance of young shoots.

The original plant in the Botanic Garden had produced flowers on several occasions, but no fruit or seeds. The cuttings taken from its roots grew rapidly, and at the end of a year's growth many of them flowered, producing shrubby stems. Some of the plants assumed a branching habit, and attained a large size. The dimensions of the largest specimen in the garden are as follows:—

* Since this paper was read a large additional number of plants have been sent from the Botanic Garden. In July 1872, 112 plants; in November 1872, 68—making in all during 1871-72, 300 plants.

Height, 16 inches; length of leaves, $6\frac{1}{2}$ inches; breadth of leaves, $3\frac{1}{4}$ inches; length of peduncle, 1 inch; circumference of stem, $\frac{3}{4}$ of an inch.

The following are the general characters of the plant cultivated in the garden:—Stem (Plate XXXI. fig. 1, *a*, *a*, *a*), more or less shrubby when fully grown, simple or branching, with marks of the leaves giving a somewhat annulated aspect, varying in height from 12 to 16 inches. The young stem is herbaceous and quadrangular (Plate XXXII. fig. 7). The plants sent from Brazil had marked rhizomes, and corresponded exactly with the figure given by Martius in his Materia Medica of Brazil, Tab. I., but those in cultivation have assumed an erect form. This may depend on the latter being restricted by potting, and being propagated from root-cuttings.

The structure of the young stem, one year old, is shown in Plate XXXII. figs. 2 and 3. In fig. 2 there is a transverse section of the stem magnified about thirty diameters, showing, externally, cellular hairs on the epidermis (*a*, *a*); next, cortical parenchyma (*b*, *b*) composed of angular cells; next, bundles of vessels (*c*, *c*), and lastly, cellular pith (*d*). In fig. 3 there is a longitudinal section of the same stem, showing a portion of the cellular tissue of the bark (*b*, *b*); the vascular bundles consisting of spiral, pitted, and woody vessels (*c*, *c*); and the central pith (*d*).

The root of the plant is about the size of a writing-quill. It is well characterised by its irregularly contorted and annulated appearance (Plate XXXI. fig. 3). The roots come off from the lower part of the shrubby stem (Plate XXXI. fig. 1, *b*, *b*, *b*). The roots may be said to combine the usual functions of the root with those of the stem, inasmuch as they are capable of producing leaf-buds; when the root is cut into pieces, each portion producing a leaf-bud, as shown in Plate XXXII. fig. 6. The outer or cortical part of the root (Plate XXXI. fig. 3, *a*, *a*) is cellular, and has small projecting rings closely applied to each other; the central part *b*, called *meditullium*, is slender, and has a firm woody structure. In Plate XXXII., figs. 4 and 5, the root structure is given; fig. 4 shows a transverse section of the root; *a*, *a*, cellular epidermal portion; *b*, *b*, cellular cortical portion, containing many granules of starch; *c*, central fibrous portion, consisting of vascular tissue. Fig. 5, longitudinal section of the root; *a*, *a*, epidermal cells; *b*, *b*, cortical starch cells; *c*, *meditullium*, or central vascular system, consisting of woody vessels marked with dots.

The leaves are entire, often with a wavy margin, opposite, with short petioles, stipulate, their form varying from oval to elliptico-lanceolate, the apex being sometimes blunt and sometimes pointed. They vary in length from 2 to 4 inches. In Plate XXXI. fig. 2, a delineation is given of an elliptical, blunt-pointed leaf of the natural size. The leaves of the plants propagated from the original specimen received from Sir W. Hooker and those from the specimens sent by Dr Gunning exhibit a difference in character. This seems to be merely

a slight variation, although conspicuous in the general aspect of the plants. The leaves in the Hookerian plant are firmer in texture, somewhat coriaceous, their form is elliptical or oval, apex rather blunt, and margin wavy. These are represented in Plate XXXI. fig. 1, and Plate XXXII. fig. 1. In the Rio Janeiro plants the leaves are thinner and more delicate in texture; the form is rather elliptico-lanceolate, the apex pointed, and the margin less wavy; in the young state the leaves are fringed with hairs; the plant grows more freely, and is less shrubby. This form is seen in Plate XXXII. fig. 7. As the plants get older, the difference in form and texture is less marked.

The stipules (Plate XXXII. fig. 8) are conspicuous, interpetiolary, opposite, united at the base, and are cut at the upper part into long narrow segments. At the base of the stipules there are several ovate-lanceolate glands (Plate XXXII. fig. 9).

The flowers are, in capitula, surrounded by a four-leaved involucre, and are supported on a stalk which is about an inch in length, at first erect, and then bent from its base downwards (Plate XXXI. fig. 4). Each capitulum contains from ten to twelve flowers, which are white, sessile, and sweet-scented. The calyx is superior, persistent, its limb cut into five divisions (Plate XXXI. fig. 5). Corolla, funnel-shaped, with a cylindrical tube and a limb divided into five broadly-ovate, pointed segments (Plate XXXI. fig. 5). Stamens, five, inserted at the upper part of the corolla, shorter than the limb (Plate XXXI. figs. 5, 6, 7, *a*). Pollen roundish (Plate XXXII. fig. 14). Pistil, consisting of an inferior bilocular ovary, with an ovule in each division; stigma bifid (Plate XXXI. figs. 5, 6, 7, *c*). The stamens and pistil are found to vary in length in different flowers. The plant is thus dimorphic. In the figure given by Sir W. Hooker in the "Botanical Magazine," the stamens are long and the style short. This character is seen in the specimens propagated from the plant in the Botanic Garden (Plate XXXI. fig. 5). In the plants produced from the Rio Janeiro specimens, two forms of flower are seen, viz., one with a short style and long stamens, as in the Hookerian plant, and another with a long style and short stamens. These two forms are seen in Plate XXXI. figs. 6 and 7, where *a* marks the stamens, and *b* the style. It is only within the last year that fruit has been produced on the plants by artificial fertilisation. In the Hookerian plant, Mr Lindsay, the house-foreman and propagator, fertilised the pistil with pollen from the same flower. Fruit was produced, but not so abundantly as in the dimorphic forms when fertilised by applying pollen from the long stamens of one flower to the long pistil of another.

In Plate XXXII. fig. 1, a representation is given of a stem (*a*) bearing elliptical wavy leaves (*b*, *b*) with short petioles, and a cluster of fruit (*c*) borne on a peduncle, which is bent downwards. The bending of the peduncle takes place after flowering, and gradually increases during fruiting, until it forms a

more or less acute angle with the lower portion of the stem. In Plate XXXII. fig. 10, there is shown the full-grown fruit (natural size) of a Rio Janeiro plant, artificially fertilised, supported on its peduncle, with the involucre at the base of the fruit. In fig 11 the fruit is magnified about one-half more than natural. The fruit is drupaceous, of a deep purple violet colour, and shining lustre. It consists of a finely coloured epicarp; a whitish, pasty, and nearly tasteless mesocarp, enclosing two hard stony nucules, each containing a hard albuminous ovate seed with a minute embryo. The fruit produced by plants with short styles (as seen in Plate XXXII. fig. 1, *c*) is short and round; that from the plants with long styles (as seen in Plate XXXII. fig. 10) is larger and slightly narrowed at the apex. In Plate XXXII. fig. 11, the two central nucules are shown, convex on the outside, and nearly flat on the inner side, with a ridge. Fig. 12 shows one of the nucules separated, exposing its inner surface with its single rib. Fig. 13 shows the hard seed, having the form of the endocarp, the cavity of which it fills completely, and having a groove on its flat surface. The albumen consists of thick-walled starch cells (Plate XXXII. fig. 15). There is a minute central embryo.

Memorandum as to the Mode of transmitting Specimens of the Ipecacuan Plant to India. [Added October 1872.]

In August 1869, Mr M'Nab made cuttings of the root of the Ipecacuan, and young plants were produced freely. Early in 1871 there was a large stock of well-grown plants, which were sent to India in Wardian cases. The construction of these and the mode of packing are detailed in Mr M'Nab's paper in the "Transactions of the Botanical Society of Edinburgh," vol. x. The plants were successfully transmitted under the care of forest officers and gardeners who happened to be going to India. In one instance cases were sent by the Messrs Lawson without any one to look after them, and the plants arrived in safety. In one of the cases sent from the Botanic Garden, every plant was in a good condition when they reached Calcutta.

At first, most of the plants were sent in earth placed in pots, well fastened down in the case. Afterwards sphagnum moss was employed, and this method is strongly recommended by Mr M'Nab. With the view of sending a large supply, the plants were taken out of the pots, wrapped round with fresh moss, and closely packed, so that a case 24 inches long and 16 broad contained easily fifty or sixty well-grown plants.

I am disposed to think it is possible to send out the roots of the Ipecacuan attached to the stem, but without leaves, in dry soil, made up of peat and sand, and that they may even be transmitted by post in a close box. Boxes with

plants in a withered state, but with the roots in dry earth, reached the garden safely from Rio Janeiro. They had been kept in a dry place, and not watered. Their roots had been dormant, and they were ready to sprout when planted out and watered. By imitating nature, and allowing the plants to remain dormant for a time, the vitality of the roots had not been destroyed, and much trouble was avoided in transport. Under-ground stems or sprouting-roots may be kept for a long time in a dry condition. If this plan were adopted, a far larger number of Ipecacuan plants, having the upper part of the stem and leaves cut off, might be transmitted in a state fit for germination and for yielding cuttings when placed in favourable circumstances as regards moisture and heat combined. The vitality of rhizomes even in a dry state is very great. Dr GEORGE HENDERSON of the Bengal Service, who is about to superintend the Calcutta Garden during Dr KING'S absence, will take with him plants prepared in this manner. I have also supplied a small box containing roots in a dry state for transmission to Calcutta through the post. If the method succeeds, there will be a great saving of trouble and expense.

There is now a good stock of plants in India, and I have no doubt that, from the roots of those now in cultivation there, a large stock of young plants may be speedily produced in Sikkim, so as to furnish an abundant supply of this most important drug for our Indian possessions. Mr ANDREW T. JAFFREY, in a letter to Sir ROBERT CHRISTISON, dated Darjeeling, 19th September 1872, states that by the end of the year he expects to be able to report that he has 2000 to 3000 plants of Ipecacuan in cultivation. I may also state that Mr LINDSAY finds that the leaves, taken from the plant and placed with their petioles in damp warm sand, and covered by a bell-glass, give off abundance of roots. It still remains to be determined whether these roots will be developed sufficiently to furnish cuttings for propagating the plant.

EXPLANATION OF PLATES XXXI. AND XXXII.

Illustrating the Form and Structure of the Ipecacuan Plant.

PLATE XXXI.

Figure 1. Plant of Ipecacuan (*Cephaëlis Ipecacuanha*, Rich.) grown in the Royal Botanic Garden of Edinburgh. It is represented about half the natural size. The stem (*a*, *a*, *a*, *a*) is woody and branching. It is, however, usually simple. The roots (*b*, *b*, *b*) come off from the lower part of the stem, and are annulated. It can be cut into sections, which produce leaf-buds, and seem to combine the characters of stem and root. The leaves (*c*, *c*, *c*) are opposite, and have oval or elliptical forms with a blunt point. From the upper part of the stem proceed peduncles bearing capitula of flowers. At first the capitula are erect, as seen in the branch to the left; while in that to the right they are bent down by a change in the direction of the peduncle.

Figure 2. Elliptical leaf, about the average natural size, having a blunt apex, with midrib and curved veins indicated by dotted lines.

Figure 3. An annulated root, slightly enlarged. This is the pharmaceutical part of the plant. The cortical portion (*a*, *a*) composed of cells containing starch grains; this portion is in the form of rings closely applied to each other. The meditullium (*b*) is the central woody portion. Processes are seen projecting from this, which are concerned in the formation of leaf-buds.

Figure 4. Capitulum, or head of gamopetalous funnel-shaped sessile flowers, white and sweet-scented, having each a five-divided limb, and being all surrounded by a four-leaved involucre. The capitulum is magnified rather more than twice the natural size.

Figure 5. Flower from the old Hookerian specimen of the plant, magnified. The corolla is split down to the base, to show the organs of reproduction. The corolla is funnel-shaped, and has a five-divided limb, with broadly ovate and pointed segments. The ovary (*c*) is inferior, and is crowned by the irregularly toothed limb of the calyx. The stamens (*a*) are five in number, and in this case are longer than the style (*b*), which terminates in a two-lobed stigma.

Figures 6 and 7 show the dimorphic flowers of the plant. (Magnified.) The two forms are required for complete fertilisation.

Figure 6. Flower taken from one of Dr Gunning's plants, showing ovary (*c*) crowned by calyx; tubular corolla, with one of the segments cut off to show the long stamens (*a*); and the short style (*b*) with stigma.

Figure 7. Another flower taken from one of Dr Gunning's plants, with a portion of the corolla removed to show the short stamens (*a*) and the long style (*b*); the ovary (*c*) is inferior.

Plate XXXII.

Figure 1. Portion of Ipecacuan plant (*Cephaëlis Ipecacuanha*), showing a somewhat shrubby stem (*a*), wavy leaves (*b*, *b*), and drupaceous fruit (c), supported on a peduncle, which is bent downwards. This is a young plant about the natural size.

Figures 2 and 3 show microscopical sections of the young stem, about one year old. The dissection made by Mr John Sadler, my assistant.

Figure 2. Transverse section of young herbaceous stem, the epidermis (*a*, *a*) shows delicate cellular hairs, the cortical portion (*b*, *b*) composed of angular cells, vascular bundles in wedges (*c*, *c*), cellular pith (*d*). Magnified about thirty diameters.

Figure 3. Longitudinal section of the same stem more highly magnified. This section does not extend to the epidermis. Cortical cells (*b*, *b*); vascular bundles (*c*, *c*), consisting of spiral, pitted, and woody tubes; hexagonal pith (*d*).

Figures 4 and 5. Sections of the root, also made by Mr Sadler.

Figure 4. Transverse section of the root (magnified), showing outer epidermal portion (*a*, *a*); the cortical portion (*b*, *b*), composed of cells containing many starch granules; central portion, meditullium (*c*), composed of wood tubes.

Figure 5. Longitudinal section of the root (magnified), showing epidermal portion (*a*, *a*), containing starchy cells (*b*, *b*); central woody and pitted vessels (*c*).

Figure 6. Two portions of the annulated root bearing leaf-buds, showing the mode in which the plant may be propagated. The root having both the functions of an ordinary root and a stem. A very small portion of a root, not larger than the $\frac{1}{8}$ of an inch, will do for the purpose of propagation.

Figure 7. Young Rio Janeiro plant, from Dr Gunning's specimens, showing somewhat quadrangular herbaceous stem, opposite, ovate, acute, delicate leaves.

Figure 8. United stipules which embrace the stem; each is divided at the apex into four long narrow segments. Magnified about six times.

Figure 9. Glands at the base of the stipules, of a somewhat ovate-lanceolate shape, composed of cells. Highly magnified.

Figure 10. Fruit of one of the Rio Janeiro plants, of the natural size; four in a cluster. The plant has dimorphic forms of flowers. It was artificially fertilised. The fruit is large, slightly narrowed towards the apex, shining, and of a deep violet purple. The succulent portion is insipid.

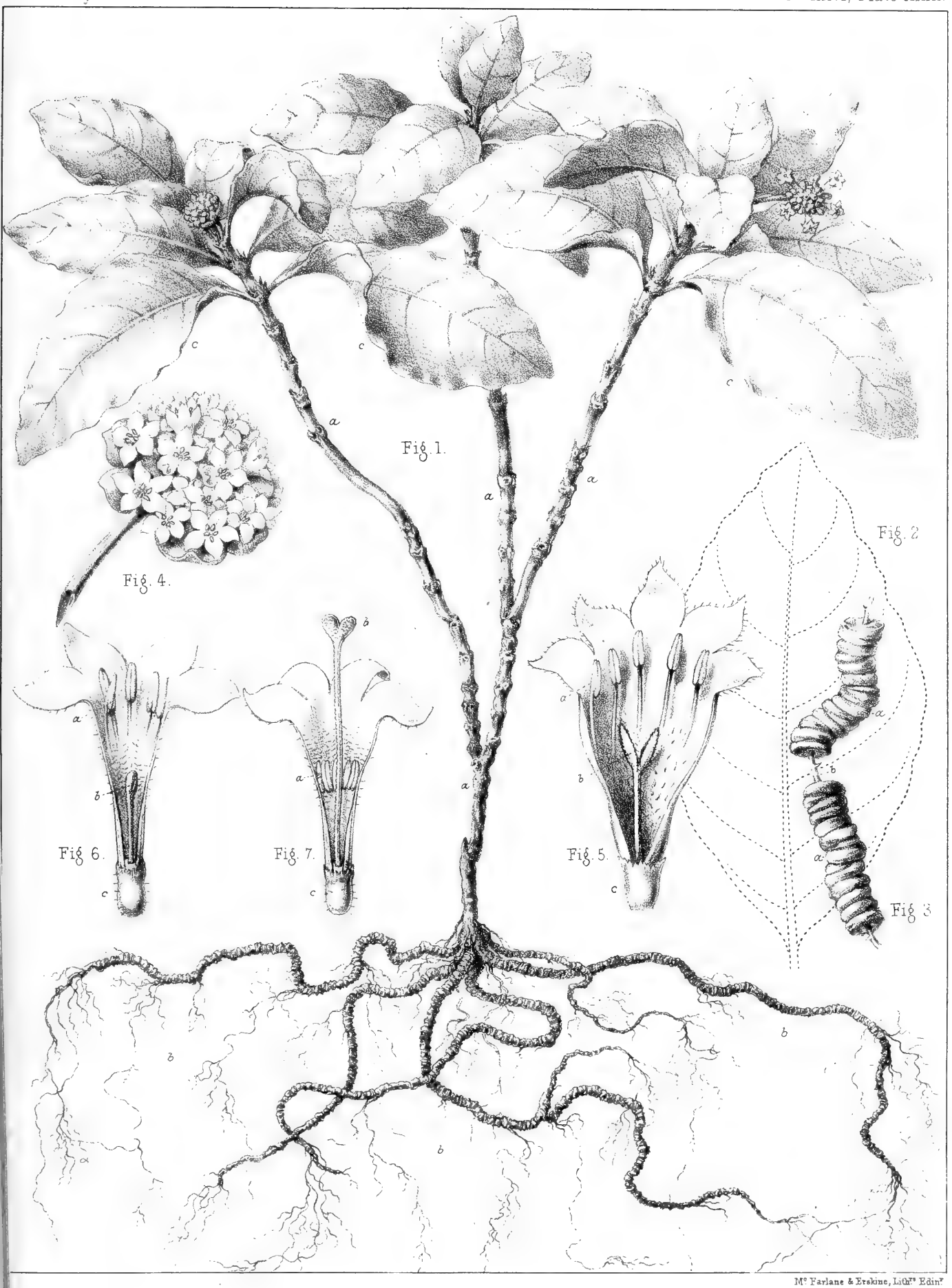
Figure 11. One of the fruits magnified about twice the natural size, showing external epicarp, which is coloured; mesocarp within, colourless; and two pale hard nucules, corresponding to divisions of the endocarp, each of which contains one hard seed.

Figure 12. One of the nucules removed, showing its flattish inner surface, with a ridge in its centre.

Figure 13. Seed shown separately, with its flat surface having a groove in its centre. It consists of hard horny albumen and a minute embryo.

Figure 14. Pollen grains, highly magnified, of a somewhat irregular rounded form.

Figure 15. Section of albumen of the seed, showing thick-walled cells, with starch grains.



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NATURAL HISTORY

Fig. 12.

Fig. 13.

Fig. 14.

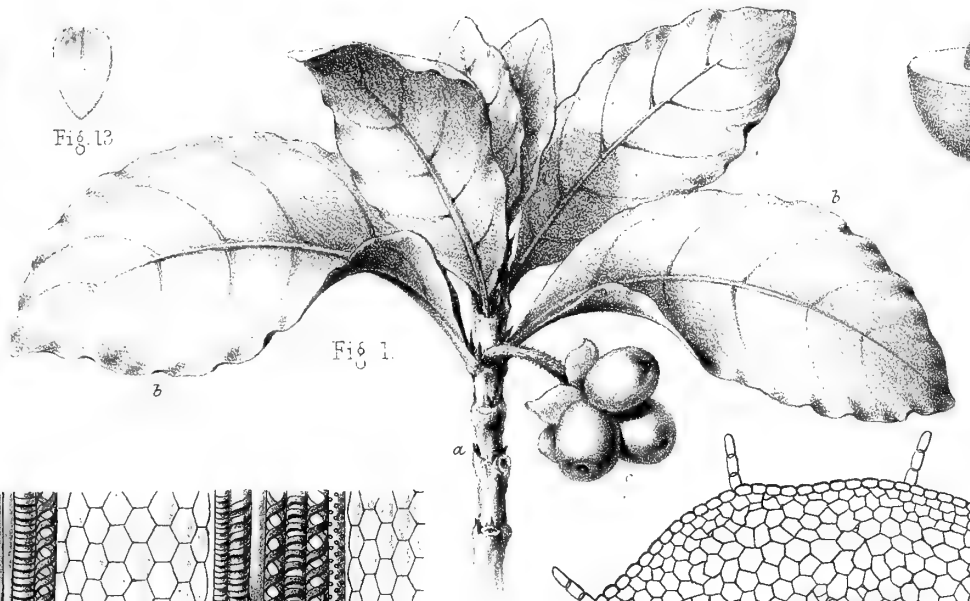


Fig. 1.

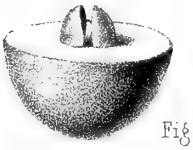
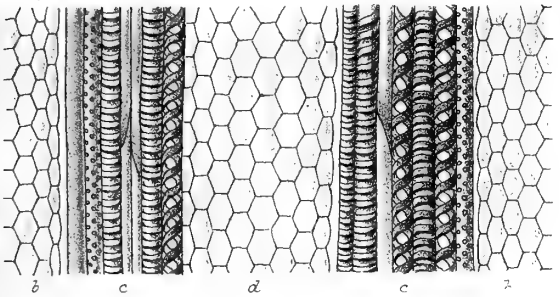


Fig. 11.

Fig. 15.

Fig. 3.



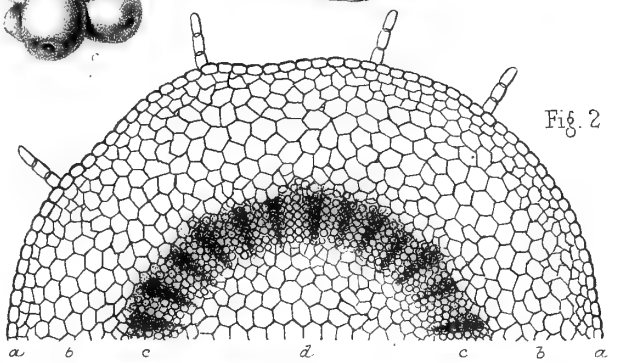
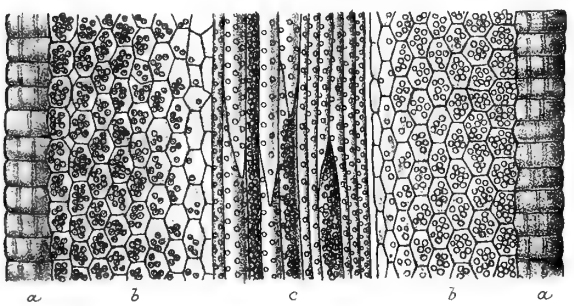


Fig. 2.



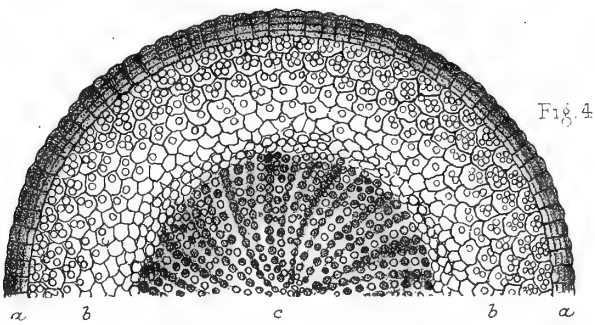


Fig. 4.

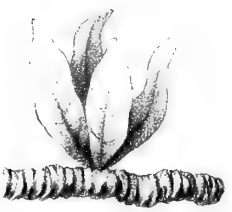


Fig. 6.

Fig. 9.

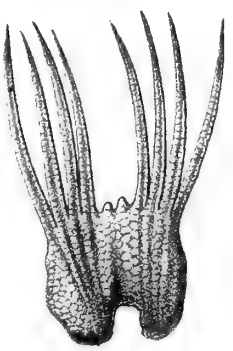


Fig. 8.

Fig. 7.

Fig. 10.

Mc Farlane & Erskine, Lith.rs Edin.r

NATURAL HISTORY.

PROCEEDINGS

OF THE

STATUTORY GENERAL MEETINGS;

AND

LIST OF MEMBERS ELECTED AT THE ORDINARY MEETINGS;

WITH

LIST OF DONATIONS TO THE LIBRARY,

From November 1869 to November 1872.

PROCEEDINGS, &c.

Monday, 22d November 1869.

At a Statutory General Meeting, Professor KELLAND, Vice-President, in the Chair, the Minutes of the Statutory Meeting of 23d November 1868 were read and confirmed.

The following Office-Bearers were elected for 1869–70:—

Professor CHRISTISON, M.D., D.C.L., President.
His Grace the DUKE of ARGYLL, Honorary Vice-Presidents.
Professor LYON PLAYFAIR, C.B.,
DAVID MILNE HOME, LL.D.
Professor KELLAND,
The Hon. LORD NEAVES,
Professor Sir WILLIAM THOMSON,
WILLIAM FORBES SKENE, Esq.,
} Vice-Presidents.
Dr JOHN HUTTON BALFOUR, General Secretary.
Professor TAIT,
Professor TURNER,
} Secretaries to Ordinary Meetings.
DAVID SMITH, Esq., Treasurer.
Dr MACLAGAN, Curator of Library and Museum.

COUNCILLORS.

GEORGE ROBERTSON, Esq., C.E.	THOMAS STEVENSON, Esq., C.E.
Professor PIAZZI SMYTH.	Dr HANDYSIDE.
PATRICK DUDGEON, Esq. of Cargen.	ARCHIBALD GEIKIE, Esq.
Dr HUGH CLEGHORN.	Professor A. CRUM BROWN.
Dr JAMES M'BAIN, R.N.	Principal Sir ALEXANDER GRANT.
Dr WILLIAM ROBERTSON.	Rev. W. LINDSAY ALEXANDER, D.D.

The TREASURER gave in his annual printed Report, certified by the Auditor.

GEORGE AULDJO JAMIESON, Esq., was elected Auditor for the year 1869–70.

The SECRETARY reported as follows:—

Number of Ordinary Fellows at November 1868,		289
New Fellows, 1868–69,		26
	Total,	315
Deduct—Deceased, 10; resigned, 2,		12
Number of Ordinary Fellows at November 1869,		303

(Signed) R. CHRISTISON, *President.*

Monday, 28th November 1870.

At a Statutory General Meeting, Dr CHRISTISON, President, in the Chair, the Minutes of the Statutory Meeting of 22d November 1869 were read and confirmed.

The following Office-Bearers were elected for 1870–71 :—

Professor CHRISTISON, M.D., D.C.L., President.
His Grace the DUKE of ARGYLL, Honorary Vice-President.
DAVID MILNE HOME, LL.D.,
Professor KELLAND,
The Hon. LORD NEAVES,
Professor Sir WILLIAM THOMSON,
WILLIAM FORBES SKENE, Esq.,
Principal Sir ALEX. GRANT, Bart.,
} Vice-Presidents.
Dr JOHN HUTTON BALFOUR, General Secretary.
Professor TAIT,
Professor TURNER,
} Secretaries to Ordinary Meetings.
DAVID SMITH, Esq., Treasurer.
Dr MACLAGAN, Curator of Library and Museum.

COUNCILLORS.

Dr JAMES M'BAIN, R.N.	Rev. W. LINDSAY ALEXANDER, D.D.
Dr WILLIAM ROBERTSON.	Professor FLEEMING JENKIN.
THOMAS STEVENSON, Esq., C.E.	Professor WYVILLE THOMSON, LL.D.
Dr HANDYSIDE.	JAMES DONALDSON, LL.D.
ARCHIBALD GEIKIE, Esq.	Dr THOMAS R. FRASER.
Professor A. CRUM BROWN.	Dr ARTHUR GAMGEE.

The TREASURER gave in his annual printed Report, certified by the Auditor.

GEORGE AULDJO JAMIESON, Esq., was elected Auditor for the year 1870–71.

The SECRETARY stated that the Council had memorialised the First Lord of H. M. Treasury relative to the establishment of a Chair of Geology in the University of Edinburgh, for which Sir RODERICK MURCHISON had offered the sum of L.6000. The memorial was laid on the table.

The SECRETARY intimated that, in conformity with the request of the Council, DAVID MILNE HOME, Esq., had kindly consented to give the Opening Address on Monday, 5th December.

The SECRETARY reported as follows :—

Number of Ordinary Fellows at November 1869,		303
New Fellows, 1869–70,		30
	Total,	333
Deduct—Deceased, 5 ; resigned, 2,	=	7
Number of Ordinary Fellows at November 1870,		326

(Signed) PHILIP KELLAND, *Vice-President.*

Monday, 27th November 1871.

At a Statutory General Meeting, Professor KELLAND, Vice-President, in the Chair, the Minutes of the Statutory Meeting of 28th November 1870 were read and confirmed.

The following Office-Bearers were elected for 1871–72 :—

Sir ROBERT CHRISTISON, Bart., M.D., D.C.L., President.
His Grace the DUKE of ARGYLL, Honorary Vice-President.
Professor KELLAND,
The Hon. LORD NEAVES.
Professor Sir WILLIAM THOMSON,
Principal Sir ALEX. GRANT, Bart.,
Sir W. STIRLING MAXWELL, Bart.,
Professor W. J. MACQUORN RANKINE,
} Vice-Presidents.
Dr JOHN HUTTON BALFOUR, General Secretary.
Professor TAIT,
Professor TURNER,
} Secretaries to Ordinary Meetings.
DAVID SMITH, Esq., Treasurer.
Dr MACLAGAN, Curator of Library and Museum.

COUNCILLORS.

Professor GEIKIE.	Dr THOMAS R. FRASER.
Professor A. CRUM BROWN.	Dr ARTHUR GAMGEE.
Rev. W. LINDSAY ALEXANDER, D.D.	ALEXANDER BUCHAN, M.A.
Professor FLEEMING JENKIN.	Professor A. DICKSON.
Professor WYVILLE THOMSON.	DAVID MILNE HOME, LL.D.
JAMES DONALDSON, LL.D.	JAMES LESLIE, Esq., C.E.

The TREASURER gave in his annual printed Report, certified by the Auditor.

GEORGE AULDJO JAMIESON, Esq., was elected Auditor for the year 1871–72.

The SECRETARY reported as follows :—

Number of Ordinary Fellows at November 1870,	. .	326
New Fellows, 1870–71,	. . . .	15
	Total,	341
Deduct—Deceased, 10; resigned, 3,	. . . =	13
Total Ordinary Fellows at November 1871,	. . .	328
Honorary Fellows deceased—British, 2; Foriegn, 1,	. Total,	3

(Signed) R. CHRISTISON, *President.*

LIST OF MEMBERS ELECTED.

December 20, 1869.

St John Vincent Day, Esq., C.E. — David Munn, Esq.
Robert R. Tatlock, Esq.

January 3, 1870.

Alexander Russel, Esq. — Dr James Crichton Browne.
Dr John Duncan. — William Burns Thomson, Esq.
Dr William R. Sanders. — Rev. Dr Andrew Thomson.
Professor Joseph Lister. — Dr William Anderson.

January 17, 1870.

Dr G. H. B. Macleod. — Dr Thomas A. G. Balfour.

February 7, 1870.

W. E. Heathfield, Esq. — Dr Edward James Shearman.
Patrick Swan, Esq. — Dr. H. Alleyne Nicholson.
Rev. Dr Hodson (re-admitted).

February 21, 1870.

Dr J. Warburton Begbie.

March 7, 1870.

John Winzer, Esq.

March 21, 1870.

Spencer C. Thomson, Esq. — Simon S. Laurie, Esq.

May 2, 1870.

James Sime, Esq. — Thomas Harvey, Esq.
John Young Buchanan, Esq. — John Hunter, Esq.
The Right Hon. The Lord Justice Clerk. — The Hon. Lord Gifford.

May 16, 1870.

James Watson, Esq. — The Hon. Lord Mackenzie.

December 5, 1870.

John Auld, Esq.

January 16, 1871.

Rev. Thomas M. Lindsay. — William Robertson Smith, Esq.
Stair Agnew, Esq.

January 30, 1871.

Dr Charles Hayes Higgins. — Dr Angus Macdonald.

February 6, 1871.

Rev. William Scott Moncrieff. — Professor A. R. Simpson.
Dr R. J. Blair Cunynghame. — Dr Cosmo Gordon Logie.

April 3, 1871.

James Geikie, Esq. Dr Thomas E. Thorpe.

April 17, 1871.

Dr John Smith, F.R.C.S.E.

May 1, 1871.

Rev. Professor Crawford.

May 15, 1871.

Thomas J. Boyd, Esq.

December 4, 1871.

Alexander H. Lee, Esq., C.E. Robert Lee, Esq., Advocate.
John Anderson, LL.D.

January 15, 1872.

David Maclagan, Esq., C.A.
Dr John Sibbald.
Rev. Andrew Tait, LL.D.
The Right Rev. Bishop Cotterill.
Major Rickard.
Dr J. G. Fleming.
David Grieve, Esq.
George Barclay, Esq.

February 5, 1872.

George Forbes, Esq., B.A. Dr J. Lindsay Stewart.
Rev. Charles R. Teape, M.A.

February 19, 1872.

Archibald Constable, Esq.

March 18, 1872.

George Seton, Esq. Captain Charles Hunter.

April 1, 1872.

James Thomson Bottomley, Esq. Thomas Knox, Esq.
Dr D. Argyll Robertson.

April 15, 1872.

Dr Thomas B. Christie.

May 20, 1872.

Rev. Hugh Macmillan, LL.D.

ALPHABETICAL LIST OF THE ORDINARY FELLOWS OF THE SOCIETY,

Corrected up to 15*th January* 1873.

N.B.—*Those marked* * *are Annual Contributors.*

1846 Alex. J. Adie, Esq., Rockville, Linlithgow
1871 *Stair Agnew, Esq, 2 Buckingham Terrace
1868 *Rev. Dr David Aitken, 4 Charlotte Square
1866 *Major-General Sir James E. Alexander of Westerton, Bridge of Allan
1867 *Rev. Dr W. Lindsay Alexander, Pinkie Burn, Musselburgh
1848 Dr James Allan, Inspector of Hospitals, Portsmouth
1856 Dr G. J. Allman, Emeritus Professor of Natural History, Wimbledon, London
1849 *David Anderson, Esq., Moredun, Edinburgh
1872 John Anderson, LL.D., 32 Victoria Road, Charlton, Kent
1845 Dr Thomas Anderson, Professor of Chemistry, University, Glasgow 10
1823 Warren Hastings Anderson, Esq., Isle of Wight
1867 *Thomas Annandale, Esq., 34 Charlotte Square
1862 *T. C. Archer, Esq., Director of the Museum of Science and Art, 5 West Newington Terrace
1849 *His Grace the Duke of Argyll, K.T., (HON. VICE-PRESIDENT), Inverary Castle
1871 *John Auld, Esq., 18 Grosvenor Crescent

1843 David Balfour, Esq., Trenaby
1835 Dr J. H. Balfour (GENERAL SECRETARY), Professor of Medicine and Botany, 27 Inverleith Row
1870 *Dr Thomas A. G. Balfour, 51 George Square
1867 *George F. Barbour, Esq., 11 George Square
1872 *George Barclay, Esq., 17 Coates Crescent 20
1858 Edmund C. Batten, M.A., Lincoln's Inn, London
1870 *Dr James Warburton Begbie, 16 Great Stuart Street
1843 Dr Bennett, Professor of Institutes of Medicine, 1 Glenfinlas Street
1861 *George Berry, Esq., 2 Windsor Terrace, Portobello
1866 *Adam Black, Esq., 38 Drummond Place
1850 *Hugh Blackburn, Esq., Prof. Mathematics, University, Glasgow
1863 *Professor Blackie, 24 Hill Street
1857 *John Blackwood, Esq., 3 Randolph Crescent
1862 *Rev. Dr W. G. Blaikie, 9 Palmerston Road
1854 Ernest Bonar, Esq. 30
1872 *James Thomson Bottomley, Esq., College, Glasgow
1869 *Robert Henry Bow, Esq., C.E., 7 South Gray Street
1871 *Thomas J. Boyd, Esq., 41 Moray Place
1864 *Dr Alex. Crum Brown, Prof. of Chemistry, 8 Belgrave Crescent
1859 *Dr John Brown, 23 Rutland Street
1861 *Rev. Thomas Brown, 16 Carlton Street
1835 William Brown, Esq., 25 Dublin Street
1870 Dr James Crichton Browne, Wakefield
1867 *A. H. Bryce, D.C.L., LL.D., 42 Moray Place
1856 *David Bryce, Esq., Architect, 131 George Street 40
1833 His Grace the Duke of Buccleuch, K.G., Dalkeith Palace
1869 *Alexander Buchan, A.M., 72 Northumberland Street
1870 *John Young Buchanan, Esq., 10 Moray Place
1857 *Dr W. M. Buchanan, 3 Carlton Terrace
1847 J. H. Burton, LL.D., Advocate, Craig House

1869 *Rev. Henry Calderwood, LL.D., Professor of Moral Philosophy, Craigrowan, Napier Road, Merchiston
1865 *Alfred R. Catton, B.A.
1866 *David Chalmers, Esq., Kate's Mill, Slateford
1860 *William Chambers, Esq. of Glenormiston, 13 Chester Street
1872 Dr Thomas B. Christie, Royal India Asylum, Ealing, London 50
1823 Sir Robert Christison, Bart., D.C.L., Professor of Materia Medica (PRESIDENT), 40 Moray Place
1863 Dr H. F. C. Cleghorn, Stravithy, St Andrews
1856 *Thomas Cleghorn, Esq., Advocate, 26 Queen Street
1844 Dr Thomas R. Colledge, Lauriston House, Cheltenham
1829 The Right Honourable Lord Colonsay, London
1829 A. Colyar, Esq.
1850 *Dr James Scarth Combe, 36 York Place

1872 *Archibald Constable, Esq., 11 Thistle Street
1843 Sir John Rose Cormack, M.D., 7 Rue d'Aguesseau, Paris
1872 *The Right Rev. Bishop Cotterill, 24 Rutland Square 60
1843 Andrew Coventry, Esq., Advocate, 29 Moray Place
1863 *Charles Cowan, Esq., Westerlea, Murrayfield
1854 *Sir James Coxe, M.D., Kinellan
1830 J. T. Gibson-Craig, Esq., W.S., 24 York Place
1829 Sir William Gibson-Craig, Bart., Riccarton
1871 *Rev. Dr Crawford, Professor of Divinity, 13 Great King Street
1853 Rev. John Cumming, D.D., London
1852 *James Cunningham, Esq., W.S., 50 Queen Street
1871 *Dr R. J. Blair Cunyninghame, 6 Walker Street
1823 Liscombe J. Curtis, Esq., Ingsdown House, Devonshire 70

1851 *E. W. Dallas, Esq., 34 Hanover Street
1841 James Dalmahoy, Esq., 9 Forres Street
1867 *David Davidson, Esq., Bank of Scotland
1848 Henry Davidson, Esq., Muirhouse
1870 *St John Vincent Day, Esq., C.E., 4 Hamilton Park Terrace, Glasgow
1867 *Francis Deas, LL.B., Advocate, 9 St Colme Street
1869 *James Dewar, Esq., 15 Gilmore Place
1869 *Alexander Dickson, M.D., Professor of Botany, University of Glasgow
1869 *William Dickson, Esq., 38 York Place
1867 Henry Dircks, LL.D., C.E., London 80
1863 *W. Dittmar, Esq.
1867 *James Donaldson, LL.D., 20 Great King Street
1866 *David Douglas, Esq., 41 Castle Street
1839 Francis Brown Douglas, Esq., Advocate, 21 Moray Place.
1868 *Rev. D. T. K. Drummond, B.A., 6 Montpelier
1867 *G. Stirling Home Drummond, Esq., Blair-Drummond
1860 *Patrick Dudgeon, Esq. of Cargen
1863 *Dr J. Matthews Duncan, 30 Charlotte Square
1870 *Dr John Duncan, 8 Ainslie Place
1851 *Sir David Dundas, Bart. of Dunira 90
1859 *Rev. Dr John Duns, 4 Mansion-House Road, Grange
1866 *Dr James Dunsmure, 53 Queen Street

1869 *George Elder, Esq., Knock Castle, Wemyss Bay
1856 *W. Mitchell Ellis, Esq., Wellington Lodge, Portobello
1855 Robert Etheridge, Esq., Clifton, Bristol
1866 *William Euing, Esq., Glasgow
1863 J. D. Everett, LL.D., Prof. Nat. Phil., Queen's College, Belfast

1866 *James Falshaw, Esq., C.E., 26 Castle Street
1859 *Dr Fayrer, Professor of Surgery, Calcutta
1868 *Robert M. Ferguson, Ph.D., 12 Moray Place 100
1858 Frederick Field, Esq., Chili
1852 Dr Andrew Fleming, H.M.I.S., Bengal
1872 *Dr J. G. Fleming, B.A., 155 Bath Street, Glasgow
1872 *George Forbes, Esq., Lecturer on Natural Philosophy, Anderson Institution, Glasgow, 4 Coates Crescent
1859 Major James George Forlong, Bombay
1828 John Forster, Esq., Liverpool
1864 *Dr John Foulerton, Manila
1858 *Professor Fraser, M.A., 20 Chester Street
1867 *Dr Thomas R. Fraser, 3 Grosvenor Street
1867 *Frederick Fuller, Esq., Professor of Mathematics, University, Aberdeen 110

1867 Dr Charles Gayner, Oxford
1867 *Dr Arthur Gamgee, 27 Alva Street
1868 J. Samson Gamgee, Esq., Birmingham
1861 *A. Geikie, Esq., Professor of Geology, Geological Survey Office, India Buildings, George IV. Bridge
1871 *James Geikie, Esq., 16 Duncan Street, Newington
1870 *Hon. Lord Gifford, Granton House
1868 *Rev. Joseph Taylor Goodsir, 11 Danube Street
1846 L. D. B. Gordon, Esq., C.E., London

1850 *Lieut.-Col. W. D. Gosset, R.E., Portsmouth
1867 *Dr Andrew Graham, R.N., 35 Melville Street. 120
1869 *Principal Sir Alex. Grant, Bart., (VICE-PRESIDENT), 21 Lansdowne Crescent
1851 *Rev. Dr James Grant, D.C.L., 15 Palmerston Place
1824 Dr Robert E. Grant, Prof. Comp. Anat., Univ. Coll., London
1872 *David Grieve, Esq., 13 Lochend Road, Leith
1860 *Dr Frederick Guthrie, M.A., Prof. of Physics, School of Mines, London
1868 *Col. Seton Guthrie, Thurso
1868 *Rev. Dr Thomas Guthrie, 1 Salisbury Road

1867 *Dr D. R. Haldane, 22 Charlotte Square
1867 *Frederick Hallard, Esq., Advocate, 61 York Place
1867 *James H. B. Hallen, Esq., Canada 130
1833 Alexander Hamilton, LL.B., W.S., The Elms, Whitehouse Loan
1837 Dr P. D. Handyside, 11 Hope Street
1854 Professor Robert Harkness, Queen's College, Cork
1869 Sir Charles A. Hartley, C.E., Sulina, Mouth of the Danube
1867 *Sir George Harvey, 21 Regent Terrace
1870 *Thomas Harvey, Esq., LL.D., 32 George Square
1859 *G. W. Hay, Esq. of Whiterigg
1855 *James Hay, Esq., 3 Links Place, Leith
1870 W. E. Heathfield, Esq., 20 King Street, St James, London
1862 *Dr James Hector, Wellington, New Zealand 140
1869 *Isaac Anderson-Henry, Esq. of Woodend, Hay Lodge, Trinity
1871 Dr Charles Hayes Higgins, Alfred House, Birkenhead
1859 Lieut. John Hills, Bombay Engineers
1828 David Milne Home, Esq. of Wedderburn, LL.D. (VICE-PRESIDENT), 10 York Place
1870 *Rev. Dr Hodson, St Andrew's College, Broadfield, Reading
1869 *Alexander Howe, Esq., W.S., 17 Moray Place
1872 *Captain Charles Hunter, Glencarse, Junior Naval and Military Club, London
1870 John Hunter, Esq., Professor of Mathematics, King's College, Windsor, Halifax
1864 *Robert Hutchison, Esq., Carlowrie Castle

1855 *The Right Hon. John Inglis, D.C.L., LL.D., Lord Justice-General, 30 Abercromby Place 150
1858 *Professor Innes, M.A., Inverleith House

1840 Edward J. Jackson, Esq., 6 Coates Crescent
1863 William Jameson, Esq., Surgeon-Major, Saharunpore
1860 *George A. Jamieson, Esq., 58 Melville Street
1825 Sir William Jardine, Bart., LL.D., of Applegarth, Jardine Hall, Lockerby
1869 *Professor H. C. Fleeming Jenkin, 5 Fettes Row
1865 *Charles Jenner, Esq., Easter Duddingston Lodge
1863 *Hon. Charles Baillie, LL.D., Lord Jerviswoode, 10 Strathearn Road
1869 Dr John Wilson Johnston, India
1867 *T. B. Johnston, Esq., 9 Claremont Crescent 160

1867 *William Keddie, Esq., 5 India Street, Glasgow
1866 *Dr Alexander Keiller, 21 Queen Street
1839 Rev. Prof. Kelland, M.A. (VICE-PRESIDENT), 20 Clarendon Crescent
1868 *Thomas Key, Esq., 42 George Square
1872 *Thomas Knox, Esq., 2 Dick Place

1868 *J. W. Laidlay, Esq., Seacliff
1870 *Simon S. Laurie, Esq., Brunstane House, Portobello
1863 *Charles Lawson, Esq., 35 George Square
1865 *Charles Lawson, jun., Esq., 35 George Square
1856 *Dr Laycock, Professor of the Practice of Medicine, 13 Walker Street 170
1872 *Alexander H. Lee, Esq., C.E., 45 Moray Place
1872 *Robert Lee, Esq., Advocate, 26 Charlotte Square
1863 *Hon. G. Waldegrave Leslie, Leslie House, Leslie
1858 *James Leslie, Esq., C.E., 2 Charlotte Square
1871 *Rev. Thomas M. Lindsay, Professor of Divinity and Church History, Free Church College, Glasgow
1861 *Dr W. Lauder Lindsay, Gilgal, Perth

1864 *William Lindsay, Esq., Hermitage-Hill House, Leith
1870 *Professor Lister, 9 Charlotte Square
1871 *Dr Cosmo Garden Logie, Surgeon Major, Royal Horse Guards
1857 Thomas Login, Esq., C.E., India 180
1861 *Professor Lorimer, Advocate, 21 Hill Street
1869 *Maurice Lothian, Esq. of St Catherine's, 54 Queen Street
1849 *Dr W. H. Lowe, Balgreen, Murrayfield

1855 *Dr Stevenson Macadam, 11 East Brighton Crescent, Portobello
1861 *Dr James M'Bain, R.N., Logie Villa, York Road, Trinity
1868 *Dr Thomas Smith Maccall, Polmont
1867 *John M. M'Candlish, Esq., 4 Doune Terrace
1866 *John M'Culloch, Esq., Banker, 11 Duke Street
1871 *Dr Angus Macdonald, 41 Northumberland Street
1820 Dr Wm. Macdonald, Prof. Civ. and Nat. Hist., St Andrews 190
1847 W. Macdonald Macdonald, Esq., St Martins
1869 *David MacGibbon, Esq., Architect, 89 George Street
1840 John Mackenzie, Esq., 11 Abercromby Place
1870 *Hon. Lord Mackenzie, 12 Great Stuart Street
1843 Dr Maclagan (CURATOR), Prof. of Medical Jurisprudence, 28 Heriot Row
1853 Lieut.-Col. R. Maclagan, Royal Engineers, Bengal
1869 *Dr R. Craig Maclagan, 5 Coates Crescent
1870 *Dr G. H. B. Macleod, Professor of Surgery, University, Glasgow
1869 *Dr William C. M'Intosh, Murthly
1872 *David Maclagan, Esq., C.A., 9 Royal Circus 200
1864 *Peter M'Lagan, Esq. of Pumpherston, M.P.
1869 *John M'Laren, Esq., Advocate, 5 Rutland Square
1868 *John F. M'Lennan, Esq., Advocate, 81 Princes Street
1872 *Rev. Hugh Macmillan, LL.D., 30 Hamilton Park Terrace, Glasgow
1866 *John Macnair, Esq., 33 Moray Place
1840 Sir John M'Neill, G.C.B.
1858 *Dr R. B. Malcolm, 126 George Street
1869 Dr Henry Marshall, Clifton, Bristol
1864 *J. D. Marwick, Esq., 10 Bellevue Crescent
1866 *Professor David Masson, 10 Regent Terrace 210
1856 *James Clerk Maxwell, Esq., Prof. Exp. Phys., Cambridge, Glenlair, Dalbeattie
1849 *Sir William Stirling-Maxwell, Bart., Keir
1863 *Edward Meldrum, Esq., Dechmont, Broxburn
1853 *Græme Reid Mercer, Esq., Ceylon Civil Service
1841 John Miller, Esq., C.E., M.P., 2 Melville Crescent
1869 *Oliver G. Miller, Esq., Panmure House, Forfarshire
1852 *Thomas Miller, Esq., A.M., LL.D., Rector, Perth Academy
1833 Admiral Sir Alexander Milne, G.C.B., Inveresk
1866 *Dr Arthur Mitchell, 5 East Claremont Street
1843 Joseph Mitchell, Esq., C.E., Viewill, Inverness 220
1865 *Dr John Moir, 52 Castle Street
1870 *The Right Hon. James Moncreiff, Lord Justice-Clerk, 15 Great Stuart Street
1871 *Rev. William Scott Moncrieff, of Fossaway, 14 George Square
1868 *Rev. James F. Montgomery, 17 Atholl Crescent
1866 *Dr Charles Morehead, 11 North Manor Place
1861 *John Muir, D.C.L., LL.D., 10 Merchiston Avenue
1870 *David Munn, Esq., 11 Gayfield Square
1857 Dr John Ivor Murray, The Knowle, near Tunbridge Wells

1856 *Hon. Lord Neaves, LL.D. (VICE-PRESIDENT), 7 Charlotte Square
1866 *Thomas Nelson, Esq., Arthursley 230
1870 *Dr Henry A. Nicholson, Prof. of Nat. Hist., Toronto
1847 James Nicol, Esq., Prof. Nat. Hist., Aberdeen
1863 *Hon. Lord Ormidale, 14 Moray Place
1837 Dr Richard Parnell, Melrose
1863 *Dr Alexander Peddie, 15 Rutland Street
1868 *John Dick Peddie, Esq., Architect, 33 Buckingham Ter.
1869 John Pender, Esq., Manchester
1849 *W. Pirrie, Esq., Professor of Surgery, Marischal College, Aberdeen
1859 *Lyon Playfair, C.B., LL.D., M.P., 4 Queensberry Place, South Kensington, London
1834 Mungo Ponton, Esq., W.S., Clifton, Bristol 240

1852 Eyre B. Powell, Esq., Director of Public Instruction, Madras
1865 *James Powrie, Esq., Reswallie, Forfar
1849 *Hon. B. F. Primrose, 22 Moray Place

1868 *Samuel Raleigh, Esq., Park House, Dick Place
1869 Rev. Thos. Melville Raven, M.A., Crakehall, Bedale
1865 *Rev. Francis Redford, M.A., Rectory, Silloth
1836 David Rhind, Esq., Architect, 54 Great King Street
1872 Major F. Ignacio Rickard, Government Inspector-General of Mines, Argentine Republic, Buenos Ayres, South America
1840 Martyn J. Roberts, Esq., Crickhowell, South Wales
1872 *Dr D. Argyll Robertson, 40 Queen Street 250
1859 *George Robertson, Esq., C.E., 47 Albany Street
1832 Dr Montgomery Robertson, Mortlake, Surrey
1860 *Dr William Robertson, 28 Albany Street
1862 *Dr E. Ronalds, Bonnington Road
1870 *Alexander Russel, Esq., 9 Chester Street
1852 *Alex. James Russell, Esq., C.S., 9 Shandwick Place
1837 J. Scott Russell, Esq, 5 Westminster Chambers, London
1869 *Dr William Rutherford, Professor of Physiology, King's College, London

1870 *Dr William R. Sanders, Prof. General Pathology, 11 Walker Street
1863 *James Sanderson, Esq., Surg.-Major, 41 Manor Place 260
1864 *Rev. D. F. Sandford, 19 Rutland Street
1849 *Edward Sang, Esq., 2 George Street
1846 Dr Schmitz, International Institution, London
1853 *Hugh Scott, Esq. of Gala, Galashiels
1864 *Professor Sellar, LL.D., 15 Buckingham Terrace
1872 *George Seton, Esq., Advocate, 42 Greenhill Gardens
1870 Dr Edward James Shearman, Moorgate, Rotherham, Yorkshire
1834 Dr Sharpey, Prof. Anatomy, Univ. Coll., London
1872 *Dr John Sibbald. 16 Dalrymple Crescent
1870 *James Sime, Esq., Craigmount House, Dick Place 270
1871 *Dr A. R. Simpson, Prof. of Midwifery, 52 Queen St.
1829 Ven. Archdeacon Sinclair, Kensington
1859 *William F. Skene, LL.D., W.S., 20 Inverleith Row
1868 *Adam Gillies Smith, Esq., C.A., 5 Lennox Street
1839 David Smith, Esq., W.S. (TREASURER), 10 Eton Ter.
1863 *Dr John Alexander Smith, 7 West Maitland Street
1866 *Dr John Smith, F.R.C.P.E., 20 Charlotte Square
1871 *Dr John Smith, F.R.C.S.E., 11 Wemyss Place
1855 *R. M. Smith, Esq., 4 Bellevue Crescent
1871 *W. R. Smith, Esq., Free Church Coll., Aberdeen 280
1846 Professor Piazzi Smyth, 15 Royal Terrace
1866 *Professor Spence, 21 Ainslie Place
1850 *Dr James Stark, 21 Rutland Street
1843 Henry Stephens, Esq., Red Braes Cottage, Bonnington
1844 David Stevenson, Esq., C.E., 45 Melville Street
1868 John J. Stevenson, Esq., Hyde Park, London
1848 Thomas Stevenson, Esq., C.E., 17 Heriot Row
1858 *Rev. Dr Stevenson, 37 Royal Terrace
1872 Dr J. Lindsay Stewart, Conservator of Forests, Punjab, India
1868 Major J. H. M. Shaw Stewart, R. Engineers, Madras 290
1869 *John L. Douglas Stewart, Esq. of Glenogil, 7 Grosvenor Crescent
1866 *Dr T. Grainger Stewart, 19 Charlotte Square
1848 *Patrick J. Stirling, Esq., LL.D., Kippendavie House

1823 Captain T. D. Stuart, H.M.I.S.
1870 *Patrick D. Swan, Esq., Kirkcaldy
1848 William Swan, Esq., Professor of Natural Philosophy St Andrews
1844 Archibald Campbell Swinton, Esq., Kimmerghame, Dunse

1872 Rev. Andrew Tait, Rector of Kilkerrin, Ireland
1861 *Professor P. Guthrie Tait, M.A. (SECRETARY), 17 Drummond Place
1870 *Robert R. Tatlock, Esq., 151 George Street, Glasgow 300
1846 Dr Taylor, Pau, France
1872 *Rev. Charles R. Teape, 15 Findhorn Place
1843 Dr Allen Thomson, Prof. Anatomy, Univ., Glasgow
1870 *Rev. Dr Andrew Thomson, 63 Northumberland Street
1842 James Thomson, Esq., C.E., Norfolk Square, Hyde Park, London
1863 *Dr Murray Thomson, Roorkee, East Indies
1864 *R. W. Thomson, Esq., C.E., 3 Moray Place
1870 *Spencer C. Thomson, Esq., 10 Chester Street.
1847 Sir William Thomson, Prof. Nat. Phil. (VICE-PRESIDENT), Glasgow
1870 *William Burns Thomson, Esq., 11 St John Street 310
1849 *William Thomas Thomson, Esq., Bonaly
1855 *Wyville Thomson, LL.D., Prof. Nat. Hist., 20 Palmerston Place
1871 *Thomas E. Thorpe, Ph.D., Lecturer on Chemistry, Anderson Institution, Glasgow
1822 Sir W. C. Trevelyan, Bart., Wallington, Morpeth
1867 *William Turnbull, Esq., 14 Lansdowne Crescent
1861 *Professor Turner, M.B. (SECRETARY), 6 Eton Terrace
1849 *Most Noble the Marquis of Tweeddale, K.T., Yester House, Haddington

1867 *Peter Waddell, Esq., 5 Claremont Park, Leith
1869 *Viscount Walden, Yester House, Haddington
1829 James Walker, Esq., W.S., Tunbridge Wells 320
1864 *William Wallace, Ph.D., Glasgow
1853 Dr James Watson, Bath
1870 *James Watson, Esq., 45 Charlotte Square
1866 *John K. Watson, Esq., 14 Blackford Road
1866 *Dr Patrick Heron Watson, 16 Charlotte Square
1862 *Rev. Robt. Boog Watson, Madeira, 4 Bruntsfield Place, Edinburgh
1840 Allan A. Maconochie Welwood, Esq. of Meadowbank and Pitliver
1869 *Captain T. P. White, Royal Engineers, 1 Drummond Place
1868 *W. Williams, Esq., Veterinary College, Clyde Street
1858 *Dr Thomas Williamson, 28 Charlotte Street, Leith 330
1834 Dr Isaac Wilson
1847 Professor John Wilson, College
1863 *Dr J. G. Wilson, 9 Woodside Crescent, Glasgow
1870 John Winzer, Esq., Assistant Surveyor, Civil Service, Ceylon
1864 *Dr Alexander Wood, 36 Moray Place
1864 *Dr Andrew Wood, 9 Darnaway Street
1855 Dr Wright, Cheltenham
1864 *Robert S. Wyld, Esq., W.S., 19 Inverleith Row

1861 *James Young, Esq., of Kelly, Wemyss Bay
1863 *Dr John Young, Professor of Natural History, Glasgow 340

Fellows elected between the commencement of the Session and the 1st January of the following year are entered under the latter date, by which their Subscriptions are regulated:—Thus, Fellows elected in December 1871 *have the date of* 1872 *prefixed to their names.*

LIST OF THE PRESENT ORDINARY MEMBERS,

Corrected up to January 15, 1873.

IN THE ORDER OF THEIR ELECTION.

PRESIDENT.

SIR ROBERT CHRISTISON, BART.

HONORARY VICE-PRESIDENT, HAVING FILLED THE OFFICE OF PRESIDENT.

HIS GRACE THE DUKE OF ARGYLL, K.T.

Date of Election.

1820 William Macdonald, M.D., F.R.C.P.E., *Professor of Natural History, St Andrews.*
1822 Sir W. C. Trevelyan, Bart., *Wallington, Northumberland.*
1823 Captain Thomas David Stuart, *of the Hon. East India Company's Service.*
Warren Hastings Anderson, Esq.
Liscombe John Curtis, Esq., *Ingsdon-House, Devonshire.*
Sir Robert Christison, Bart., M.D., *Professor of Materia Medica.*
1824 Robert E. Grant, M.D., *Professor of Comparative Anatomy, University College, London.*
1828 John Forster, Esq., *Architect, Liverpool.*
David Milne Home, LL.D., *Advocate, of Milne-Graden and Wedderburn.*
1829 A. Colyar, Esq.
Right Hon. Sir William Gibson-Craig, Bart. *of Riccarton.*
Right Hon. Lord Colonsay.
Venerable Archdeacon Sinclair, *Kensington.*
James Walker, Esq., W.S.
1830 J. T. Gibson-Craig, Esq., W.S.
1832 Montgomery Robertson, M.D.
1833 Admiral Sir Alexander Milne, R.N., G.C.B.
His Grace the Duke of Buccleuch, K.G., *Dalkeith Palace.*
Alexander Hamilton, LL.B., W.S.
1834 Mungo Ponton, Esq., W.S., *Clifton, Bristol.*
Isaac Wilson, M.D., F.R.S., Lond.
William Sharpey, M.D., LL.D., F.R.S., *Professor of Anatomy, University College, London.*
1835 John Hutton Balfour, A.M., M.D., F.R.S., *Professor of Medicine and Botany.*
William Brown, Esq., F.R.C.S.E.
1836 David Rhind, Esq., *Architect.*

Date of Election.

1837 John Scott Russell, A.M., *London.*
Richard Parnell, M.D.
Peter D. Handyside, M.D., F.R.C.S.E.

1839 David Smith, Esq., W.S.
Rev. Philip Kelland, A.M., F.R.S., *Professor of Mathematics.*
Francis Brown Douglas, Esq., *Advocate.*

1840 Alan A. Maconochie Wellwood, Esq., *of Meadowbank and Pitliver.*
Martyn J. Roberts, Esq., *Crickhowell, South Wales.*
Sir John M'Neil, G.C.B., LL.D.
Edward J. Jackson, Esq.
James Mackenzie, Esq.

1841 John Miller, Esq., *of Leithen.*
James Dalmahoy, Esq.

1842 James Thomson, Esq., *Civil Engineer, London.*

1843 A. D. Maclagan, M.D., *Professor of Medical Jurisprudence.*
Sir John Rose Cormack, M.D., F.R.C.P.E., 7 *Rue d'Aguesseau, Paris.*
Allen Thomson, M.D., F.R.S., *Professor of Anatomy, Glasgow.*
Joseph Mitchell, Esq., *Civil Engineer, Viewhill, Inverness.*
Andrew Coventry, Esq., *Advocate.*
John Hughes Bennett, M.D., *Professor of Physiology.*
D. Balfour, Esq., *of Trenaby.*
Henry Stephens, Esq.

1844 Archibald Campbell Swinton, Esq., *of Kimmerghame.*
David Stevenson, Esq., *Civil Engineer.*
Thomas R. Colledge, M.D., F.R.C.P.E.

1845 Thomas Anderson, M.D., *Professor of Chemistry, Glasgow.*

1846 A. Taylor, M.D., *Pau.*
Alexander J. Adie, Esq., *Civil Engineer.*
L. D. B. Gordon, Esq., C.E., *London.*
L. Schmitz, LL.D., Ph.D., *International Institution, London.*
Charles Piazzi Smyth, Esq., F.R.S., *Professor of Practical Astronomy.*

1847 Sir William Thomson, M.A. Camb., LL.D., F.R.S., *Professor of Natural Philosophy, Glasgow.*
John Hill Burton, LL.D., *Advocate.*
James Nicol, Esq., *Professor of Natural History, Aberdeen.*
William Macdonald Macdonald, Esq., *of St Martins.*
John Wilson, Esq., *Professor of Agriculture.*

1848 Thomas Stevenson, Esq., C.E.
James Allan, M.D., *Inspector of Hospitals, Portsmouth.*
Henry Davidson, Esq.
William Swan, Esq., *Professor of Natural Philosophy, St Andrews.*
Patrick James Stirling, LL.D.

1849 Sir William Stirling-Maxwell, Bart., *of Keir and Pollok.*

1849 William Thomas Thomson, Esq.
W. H. Lowe, M.D., F.R.C.P.E., *Balgreen.*

Date of Election.

1849 Honourable Bouverie F. Primrose.
David Anderson, Esq., *of Moredun.*
W. R. Pirrie, M.D., *Professor of Surgery, Aberdeen.*
His Grace the Duke of Argyll, K.T., *Inverary Castle.*
The Most Noble the Marquis of Tweeddale, K.T., *Yester House.*
Edward Sang, Esq.

1850 James Stark, M.D., F.R.C.P.E. (Re-admitted.)
Lieutenant-Colonel W. Driscoll Gosset, R.E.
Hugh Blackburn, Esq., *Professor of Mathematics, Glasgow.*
James Scarth Combe, M.D., F.R.C.S.E.

1851 Sir David Dundas, Bart., *of Dunira.*
E. W. Dallas, Esq.
Rev. James Grant, D.D., D.C.L., *one of the Ministers of Edinburgh.*

1852 Eyre B. Powell, Esq., *Madras.*
Thomas Miller, A.M., LL.D., *Rector, Perth Academy.*
James Cunningham, Esq., W.S.
Alexander James Russell, Esq., C.S.
Andrew Fleming, M.D., *Bengal.*

1853 James Watson, M.D., *Bath.*
Lieutenant-Colonel Robert Maclagan, *Bengal Engineers.*
Rev. John Cumming, D.D., *London.*
Hugh Scott, Esq., *of Gala.*
Græme Reid Mercer., Esq.

1854 Robert Harkness, Esq., *Professor of Mineralogy and Geology, Queen's College, Cork.*
Sir James Coxe, M.D., F.R.C.P.E.
Ernest Bonar, Esq.

1855 Stevenson Macadam, Ph.D.
Robert Etheridge, Esq.. *Clifton, Bristol.*
Right Honourable John Inglis, D.C.L., LL.D., *Lord Justice-General.*
Wyville T. C. Thomson, LL.D., *Professor of Natural History.*
Thomas Wright, M.D., *Cheltenham.*
James Hay, Esq.
R. M. Smith, Esq.

1856 David Bryce, Esq.
William Mitchell Ellis. Esq.
George J. Allman, M.D., F.R.S., *Emeritus Professor of Natural History.*
Honourable Lord Neaves, LL.D.
Thomas Laycock, M.D., *Professor of the Practice of Medicine.*
Thomas Cleghorn, Esq., *Advocate, Sheriff of Aryyleshire.*
James Clerk Maxwell, Esq., F.R.S., *Professor of Experimental Physics, Cambridge.*

1857 John Ivor Murray, M.D., F.R.C.S.E.
John Blackwood, Esq.
W. M. Buchanan, M.D.
Thomas Login, Esq., C.E.

Date of Election.

1857 Edmund C. Batten, M.A., *Lincoln's Inn, London.*

1858 Thomas Williamson, M.D., F.R.C.S.E., *Leith.*

Robert B. Malcolm, M.D., F.R.C.P.E.

Frederick Field, Esq., *Chili.*

James Leslie, Esq., C.E.

Cosmo Innes, Esq., *Professor of History.*

Alexander Campbell Fraser, M.A., *Professor of Logic.*

Rev. William Stevenson, D.D.

1859 William F. Skene, LL.D.

G. W. Hay, Esq., *of Whiterigg.*

Joseph Fayrer, M.D., F.R.C.S.E., *Professor of Surgery, Calcutta.*

George Robertson, Esq., C.E.

Lyon Playfair, C.B., Ph.D., F.R.S., M.P., 4 *Queensberry Place, South Kensington, London, W.*

John Brown, M.D., F.R.C.P.E.

Rev. John Duns, D.D.

Lieutenant John Hills, *Bombay Engineers.*

Major James George Forlong.

1860 William Robertson, M.D., F.R.C.P.E.

Frederick Guthrie, M.D., *Professor of Physics, School of Mines, London.*

George A. Jamieson, Esq.

Patrick Dudgeon, Esq., *of Cargen.*

William Chambers, Esq., *of Glenormiston.*

1861 Rev. Thomas Brown.

James M'Bain, M.D., R.N.

Peter Guthrie Tait, A.M., *Professor of Natural Philosophy.*

John Muir, D.C.L., LL.D.

William Turner, M.B., *Professor of Anatomy.*

William Lauder Lindsay, M.D.

James Lorimer, A.M., *Professor of Public Law.*

Archibald Geikie, Esq., F.R.S., *Director of the Geological Survey, Scotland.*

George Berry, Esq.

James Young, Esq.

1862 Rev. William G. Blaikie, D.D.

Edmund Ronalds, Ph.D.

Thomas C. Archer, Esq., *Director of Museum of Science and Art.*

James Hector, M.D., *Wellington, New Zealand.*

Rev. Robert Boog Watson, *Madeira.*

1863 H. F. C. Cleghorn, M.D., *Stravithy, St Andrews.*

John Stuart Blackie, Esq., *Professor of Greek.*

Edward Meldrum, Esq.

1863 Charles Lawson, Esq., *of Borthwick Hall.*

Alexander Peddie, M.D., F.R.C.P.E.

William Jameson, Esq., *Surgeon-Major, Saharunpore.*

Murray Thomson, M.D., *Roorkie, India.*

Date of Election.

1863 John Young, M.D., *Professor of Natural History, University of Glasgow.*
J. G. Wilson, M.D., F.R.C.S.E.
J. Matthews Duncan, M.D., F.R.C.P.E.
W. Dittmar, Esq.
Honourable Lord Ormidale.
Joseph D. Everett, D.C.L., *Professor of Natural Philosophy, Queen's College, Belfast.*
Honourable G. Waldegrave Leslie, *Leslie House.*
Honourable Charles Baillie, Lord Jerviswoode.
James Sanderson, Esq., *Surgeon-Major.*
Charles Cowan, Esq.
John Alexander Smith, M.D., F.R.C.P.E.

1864 Alex. Crum Brown, M.D., D.Sc., *Professor of Chemistry.*
Alex. Wood, M.D., F.R.C.P.E.
Andrew Wood, M.D., F.R.C.S.E.
Robert William Thomson, Esq., C.E.
James David Marwick, Esq.
Rev. Daniel F. Sandford.
Robert S. Wyld, Esq., W.S.
Peter M'Lagan, Esq., *of Pumpherston*, M.P.
William Lindsay, Esq.
W. Y. Sellar, M.A., *Professor of Humanity.*
Robert Hutchison, Esq., *Carlowrie Castle.*
William Wallace, Ph.D.
John Foulerton, M.D., F.R.C.S.E., *Manilla.*

1865 Alfred R. Catton, M.A. Camb.
Rev. Francis Redford, M.A., *Rector of Silloth.*
John Moir, M.D., F.R.C.P.E.
James Powrie, Esq., *of Reswallie, Forfar.*
Charles Jenner, Esq.
Charles Lawson, jun., Esq.

1866 Alexander Keiller, M.D., F.R.C.P.E.
William Euing, Esq.
John M'Culloch, Esq.
T. Grainger Stewart, M.D., F.R.C.P.E.
Major-General Sir James E. Alexander, *of Westerton.*
Charles Morehead, M.D.
David Masson, M.A., *Professor of Rhetoric and English Literature.*
David Douglas, Esq.
John Macnair, Esq.
James Spence, Esq., F.R.C.S.E., *Professor of Surgery.*
Thomas Nelson, Esq.
Adam Black, Esq.
James Dunsmure, M.D., F.R.C.S.E.
Arthur Mitchell, M.D.

Date of Election.

1866 Patrick Heron Watson, M.D., F.R.C.S.E.
John Smith, M.D., F.R.C.P.E.
John Falshaw, Esq., C.E.
John K. Watson, Esq.
David Chalmers, Esq.
1867 T. B. Johnston, Esq.
George F. Barbour, Esq., *of Bonskeid.*
David Davidson, Esq.
Peter Waddell, Esq.
Sir George Harvey.
George Stirling Home Drummond, Esq., *of Blair-Drummond.*
Frederick Fuller, *Professor of Mathematics, Aberdeen.*
Andrew Graham, M.D., R.N.
William Turnbull, Esq.
Archibald Hamilton Bryce, D.C.L., LL.D.
Francis Deas, LL.B., *Advocate.*
Arthur Gamgee, M.D.
Sheriff Hallard.
Thomas R. Fraser, M.D.
Thomas Annandale, Esq., F.R.C.S.E.
D. R. Haldane, M.D., F.R.C.P.E.
John M. M'Candlish, Esq.
James Donaldson, LL.D., *Rector of the High School.*
James H. B. Hallen, Esq., *India.*
Henry Dircks, Esq., C.E., *London.*
Charles Gayner, M.D., *Oxford.*
William Keddie, Esq., *Glasgow.*
Rev. W. Lindsay Alexander, D.D.
1868 John F. M'Lennan, Esq., *Advocate.*
Rev. David Aitken, D.D.
Robert M. Ferguson, Ph.D.
J. W. Laidlay, Esq., *of Seacliff.*
W. Williams, Esq., *Veterinary College.*
J. Samson Gamgee, Esq., *Birmingham.*
Rev. D. T. K. Drummond, B.A. Oxon.
Rev. Joseph Taylor Goodsir.
Major J. H. M. Shaw Stewart, *Royal Engineers, Madras.*
John J. Stevenson, Esq.
Very Rev. Dean Montgomery.
1868 John Dick Peddie, Esq., *Architect.*
Colonel Seaton Guthrie.
Samuel Raleigh, Esq.
Thomas Smith Maccall, M.D., *Polmont.*
Rev. Thomas Guthrie, D.D.

Date of Election.

1868 Thomas Key, Esq.
Adam Gillies Smith, Esq., C.A.
1869 Oliver G. Miller, Esq.
John Leveson Douglas Stewart, Esq., *of Nateby Hall.*
Alexander Buchan, Esq.
H. C. Fleeming Jenkin, Esq., *Professor of Engineering.*
William Dickson, Esq.
John Pender, Esq., *Manchester.*
Isaac Anderson-Henry, Esq., *of Woodend.*
George Elder, Esq., *Knock Castle, Wemyss Bay.*
Sir Charles A. Hartley, C.E., *Sulina, Mouth of the Danube.*
David MacGibbon, Esq., *Architect.*
Rev. Thomas Melville Raven, M.A., *Crakehall, Bedale.*
Alexander Howe, Esq., W.S.
Viscount Walden, *Yester House.*
Alexander Dickson, M.D., *Professor of Botany, University of Glasgow.*
William C. M'Intosh, M.D., *Murthly.*
Henry Marshall, M.D., *Clifton, Bristol.*
William Rutherford, M.D., *Professor of Physiology, King's College, London.*
R. Craig Maclagan, M.D.
James Dewar, Esq.
Rev. Henry Calderwood, LL.D., *Professor of Moral Philosophy.*
Sir Alexander Grant, Bart., LL.D., *Principal of the University of Edinburgh.*
Captain T. P. White, *Royal Engineers.*
John Wilson Johnston, M.D., *India.*
Robert Henry Bow, Esq., C.E.
Maurice Lothian, Esq., *of St Catherine's.*
John M'Laren, Esq., *Advocate.*
1870 St John Vincent Day, Esq., C.E., *Glasgow.*
David Munn, Esq.
Robert R. Tatlock, Esq., F.C.S., *Glasgow.*
Alexander Russel, Esq.
James Crichton Browne, M.D., *West Riding Asylum, Wakefield.*
John Duncan, M.D.
William Burns Thomson, Esq., F.R.C.S.
William R. Sanders, M.D., *Professor of General Pathology.*
Rev. Andrew Thomson, D.D.
Joseph Lister, Esq., F.R.S., *Professor of Clinical Surgery.*
G. H. B. Macleod, M.D., *Regius Professor of Surgery, University, Glasgow.*
1870 Thomas A. G. Balfour, M.D., F.R.C.P.E.
W. E. Heathfield, Esq., F.R.G.S., F.C.S., *London.*
Edward James Shearman, M.D., F.R.C.P., F.R.C.S. Eng.
Patrick D. Swan, Esq., *Kirkcaldy.*
H. Alleyne Nicholson, M.D., D.Sc., M.A., *Toronto.*

Date of Election.

1870 Rev. James S. Hodson, D.D., *St Andrew's College, Broadfield, Reading.* (Re-admitted
James Warburton Begbie, M.D.
John Winzer, Esq., *Assistant Surveyor, Ceylon Civil Service, Galle, Ceylon.*
Spencer C. Thomson, Esq., B.A., *Actuary.*
Simon S. Laurie, Esq.
James Sime, Esq.
Thomas Harvey, LL.D., M.A., *Rector, Edinburgh Academy.*
John Young Buchanan, Esq., M.A.
John Hunter, Esq., M.A., F.C.S.
Sir James Moncreiff, *Lord Justice-Clerk.*
Hon. Lord Gifford.
James Watson, Esq.
Hon. Lord Mackenzie.

1871 John Auld, Esq., W.S.
Rev. Thomas M. Lindsay, *Glasgow.*
Rev. William Robertson Smith, M.A., *Aberdeen.*
Stair Agnew, Esq.
Charles Hayes Higgins, M.D., M.R.C.P., F.R.C.S., *Birkenhead, Cheshire.*
Angus Macdonald, M.D.
Rev. William Scott Moncrieff, *of Fossaway.*
Alexander R. Simpson, *Professor of Midwifery.*
R. J. Blair Cunynghame, M.D.
Cosmo Gordon Logie, M.D., *Surgeon-Major, Royal Horse Guards.*
James Geikie, Esq., *Surveyor of Geological Survey of Scotland.*
Thomas Ed. Thorpe, Ph.D., *Lecturer on Chemistry, Anderson's Institution, Glasgow.*
John Smith, M.D., F.R.C.S.E.
Rev. Thomas J. Crawford, *Professor of Divinity.*
Thomas J. Boyd, Esq.

1872 Alexander H. Lee, Esq., *Civil Engineer.*
Robert Lee, Esq., *Advocate.*
John Anderson, LL.D., *Victoria Road, Charlton, Kent.*
David Maclagan, Esq., C.A., F.S.S.
Major F. Ignacio Rickard, F.G.S., *Inspector-General of Mines, Buenos Ayres.*
John Sibbald, M.D.
J. G. Fleming, M.D., *Glasgow.*
Rev. Andrew Tait, LL.D., *Rector of Kilkerrin, Ireland.*
David Grieve, Esq.
Right Rev. Bishop Cotterill.
George Barclay, Esq.
George Forbes, Esq., B.A., *Lecturer on Natural Philosophy, Anderson's Institution, Glasgow.*
J. Lindsay Stewart, M.D., F.R.C.S., F.L.S., F.R.G.S., *Punjaub, India.*
Rev. Charles R. Teape, M.A., Ph.D.
Archibald Constable, Esq.
George Seton, Esq., M.A. Oxon., *Advocate.*

Date of Election.

1872 Captain Charles Hunter, *London.*

James Thomson Bottomley, Esq., M.A., *Lecturer on Natural Philosophy, University, Glasgow.*

Thomas Knox, Esq.

D. Argyll Robertson, M.D.

Thomas B. Christie, M.D., M.R.C.P. Lond., F.R.C.P. Edin., *Ealing, London.*

Rev. Hugh Macmillan, LL.D., *Glasgow.*

NON-RESIDENT MEMBER,

ELECTED UNDER THE OLD LAWS.

Sir Richard Griffiths, Bart., Dublin.

LIST OF HONORARY FELLOWS.

His Royal Highness the Prince of Wales.

FOREIGNERS (LIMITED TO THIRTY-SIX BY LAW X.)

	Louis Agassiz,	*Cambridge, Massachusetts.*
	J. B. A. L. Léonce Elie de Beaumont,	*Paris.*
	Claude Bernard,	*Do.*
	Robert Wilhelm Bunsen,	*Heidelberg.*
5	Michael Eugene Chevreul,	*Paris.*
	James D. Dana, LL.D.,	*Newhaven, Connecticut.*
	Jean Baptiste Dumas,	*Paris.*
	Charles Dupin,	*Do.*
	Christian Gottfried Ehrenberg,	*Berlin.*
10	Elias Fries,	*Upsala.*
	François Pierre Guillaume Guizot,	*Paris.*
	Christopher Hansteen,	*Christiania.*
	Herman Helmholtz,	*Heidelberg.*
	Gustav Robert Kirchhoff,	*Do.*
15	Albert Kölliker,	*Wurzburg.*
	Johann von Lamont,	*Munich.*
	Richard Lepsius,	*Berlin.*
	Rudolph Leuckart,	*Leipzig.*
	Urbain Jean Joseph Leverrier,	*Paris.*
20	Baron Justus von Liebig,	*Munich.*
	Henry Milne-Edwards,	*Paris.*
	Theodore Mommsen,	*Berlin.*
	Prof. Benjamin Peirce,	*United States Survey.*
	Adolphe Pictet,	*Geneva.*
25	Lambert Adolphe Jacques Quetelet	*Brussels.*

	M. Le Comte De Remusat,	*Paris.*
	Henry Victor Regnault,	*Do.*
	Auguste De la Rive,	*Geneva.*
	Gustav Rose,	*Berlin.*
30	Angelo Secchi,	*Rome.*
	Karl Theodor von Siebold,	*Munich.*
	Bernard Studer,	*Berne.*
	Rudolph Virchow,	*Berlin.*
34	Friedrich Wohler	*Gottingen.*

BRITISH SUBJECTS (LIMITED TO TWENTY BY LAW X.)

	John Couch Adams, Esq.,	*Cambridge.*
	Sir George Biddell Airy,	*Greenwich.*
	Thomas Andrews, M.D.,	*Belfast (Queen's College).*
	Thomas Carlyle, Esq.,	*London.*
5	Arthur Cayley, Esq.,	*Cambridge.*
	Charles Darwin, Esq.,	*Down, Bromley, Kent.*
	James Prescott Joule, LL.D.,	*Cliffpoint, Higher Broughton, Manchester.*
	William Lassell, Esq.,	*Liverpool.*
	Rev. Dr Humphrey Lloyd,	*Dublin.*
10	Sir William E. Logan,	*London.*
	Sir Charles Lyell, Bart.,	*Do.*
	John Stuart Mill, Esq.,	*Do.*
	Richard Owen, Esq.,	*Do.*
	Lieut.-General Edward Sabine, R.A.,	*Do.*
15	George Gabriel Stokes, Esq.,	*Cambridge.*
	William Henry Fox Talbot, Esq.,	*Lacock Abbey, Wiltshire.*
	Alfred Tennyson, Esq.,	*Freshwater, Isle of Wight.*
18	Sir Charles Wheatstone, D.C.L.,	*London.*

LIST OF FELLOWS DECEASED AND RESIGNED,

FROM NOVEMBER 1869 TO NOVEMBER 1872.

HONORARY FELLOWS DECEASED (FOREIGN).

Wilhelm Carl Haidinger, *Vienna.*
Hugo von Mohl, *Tubingen.*

HONORARY FELLOWS DECEASED (BRITISH).

Sir John Frederick William Herschel, Bart.
Sir Roderick Impey Murchison, K.C.B.

ORDINARY FELLOWS DECEASED.

William Anderson, LL.D.
Charles Babbage, Esq.
Honourable Lord Barcaple.
Thomas Barnes, M.D.
Robert Chambers, LL.D.
Robert Daun, M.D.
Adam Hunter, M.D.
Alexander Keith Johnston, LL.D.
Patrick Miller, M.D.
Sheridan Muspratt, M.D.
Robert Nasmyth, Esq.
Sir William Scott, Bart.
Sir James Simpson, Bart., *Professor of Midwifery.*
Moses Steven, Esq., *of Bellahouston.*
James Syme, Esq., *Professor of Clinical Surgery.*
John Addington Symonds, M.D.
Robert Russell, Esq.
Right Rev. Bishop Terrot.
Fraser Thomson, M.D.

ORDINARY FELLOWS RESIGNED.

W. A. F. Browne, Esq.
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